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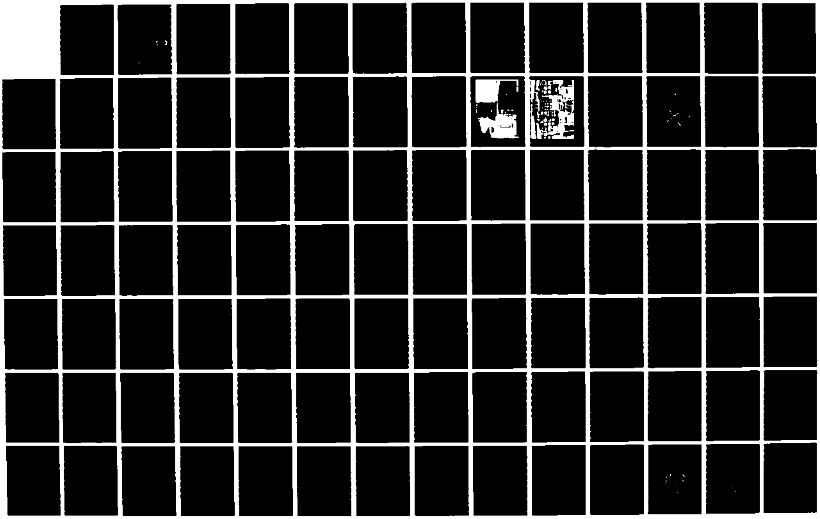

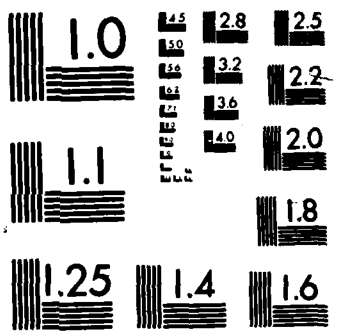
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FAA TECHNICAL CENTER
Atlantic City Airport
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Comprehensive Test and Evaluation of the Dalmo Victor TCAS II Industry Prototype

Albert J. Rehmann

February 1986

Final Report

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16. Abstract

This document describes the test conduct and results of a five-part comprehensive evaluation of two prototype minimum Traffic Alert and Collision Avoidance System (TCAS) II units. The five parts include: (1) hardware and software verification, (2) cockpit display and operational procedure verification, (3) pilot and inflight observer training, (4) TCAS II demonstration to the aviation community, and (5) readiness for airworthiness certification testing.

Overall, the minimum TCAS II prototype has matured into an acceptable test-bed for the 8-month inservice evaluation in a commercial airliner. System reliability has improved and pilot acceptance was generally good. It is expected that minimum TCAS II will provide a valuable service to airline pilots.

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EXECUTIVE SUMMARY

This report describes the comprehensive evaluation of the Industry Prototype Traffic Alert and Collision Avoidance System (TCAS) II built by Dalmo Victor in Belmont, California, under Federal Aviation Administration (FAA) contract DTFA01-C-81-10089 and completes the requirements of Program Directive (PD) No. T11-01A.

The evaluation of the prototype TCAS began at the factory with expanded test scope and procedures outlined in the Technical Center's TCAS evaluation project plan (table 1, item 2). The purpose of the expanded factory test was to exercise the system with those prepared to troubleshoot present problems. The acceptance testing consisted of hardware tests including radio frequency (RF) and reply processor subsystem tests, interface and display tests, and magnetic tape recording density tests. Software and Collision Avoidance System (CAS) logic tests were added by means of encounter senarios using simulated targets. Many system deficiencies were discovered in the CAS logic tests.

The first prototype (SN01) was shipped to the Technical Center in May 1983. It was installed in the FAA Boeing 727 along with the Lincoln Laboratory Display (AID) and FAA-fabricated control panel (the TCAS display system and control panel manufactured by Dalmo Victor was not ready for shipment until August 1983). From May to July the prototype underwent an extensive engineering evaluation. Several problems were discovered and corrected by Dalmo Victor. In July, when the prototype reached a consistent level of performance, subject pilots from the industry were invited to the Technical Center to participate in an operational evaluation. After the third subject pilot completed his mission, the prototype was returned to the factory. In August 1983, a second prototype (SN02) was fabricated and ready for testing along with a TCAS display system and control panel. After a comprehensive factory acceptance test, it was shipped to the Technical Center. Thus, the Center's evaluation was divided into two parts: from May to July, SN01, and from August to May 1984, SN02. An engineering evaluation, followed by a subject pilot operational evaluation, was conducted on SN02. The engineering evaluation of SN01 and SN02 consisted of bench tests, ramp tests, and flight tests. The bench test measurements included transmitter power output, frequency, whisper shout attenuator accuracy, pulse shape, receiver sensitivity, gain center frequency, and bandwidth. All measurements were made at least twice on separate days to check the reliability of the prototypes. Ramp measurements included receiver antenna patterns and transmitted pulse amplitudes. Flight measurements included surveillance performance and CAS logic performance, in both encounter missions with chase aircraft and in approach missions with targets of opportunity.

The results of the engineering evaluation were:

1. Bench tests: the prototypes were reliable except for receiver degradation. In each TCAS at least two receiver gains and/or slopes decreased by 2 decibels (dB) from one measurement to the next.

2. Ramp test: serial numbers two and five antennas were found to have radiation patterns which shifted from the design values.

3. Flight test: logic errors or coding errors which were found were reported and tracked by means of the trouble report (TR) system, and were ultimately resolved.

In November 1983, subject pilots were invited from the airlines and various FAA organizations to participate in an operational evaluation. They arrived in groups of two, received 1 day of ground school training, and then flew 2 days of missions. The first day (weather permitting) was scheduled for planned encounters with one or two Center aircraft. The second day was scheduled for approaches into a nearby airport such as Philadelphia or Newark. Occasionally, bad weather over the Technical Center postponed the encounter mission, and approaches were made to an airport where the weather was clear. A total of 13 subject pilots participated in the operational evaluation.

Overall, pilot reaction was good; pilots were asked to judge TCAS in four areas: usefulness, timeliness, correctness, necessary, and to rate the TCAS overall using a 5 anchor scale from -2 to +2. The overall ratings were: <u>useful</u> "yes" = 91 percent, "no" = 9 percent, <u>timely</u> "yes" = 82 percent, "no" = 18 percent; <u>necessary</u> "yes" = 63 percent, "no" = 37 percent; <u>correct</u> "yes" = 84 percent, "no" = 16 percent. On a scale of -2 to +2, the pilots rated TCAS a +1. Several changes were recommended by the subject pilots including: (1) changing the IVSI direction arrows from red to green, and (2) altering the spoken phrases to eliminate the words "don't" and "limit" in the resolution advisory emunication because (a) "fly to red" is inconsistent with pilot instincts, and (b) the pilots missed the words "don't" or "limit" preceeding the words descend or climb and, therefore, attempted to maneuver in the wrong direction. The subject pilots also criticized the traffic advisory display indicating that the color red is hard to see, and that the display washes out in sunlight. No immediate correction is envisioned for the display visibility, however, the IVSI arrows were changed to green, and the spoken phrases changed to "limit vertical rate."

After the subject pilot evaluation, a national tour was completed where the TCAS equipped B-727 was flown to five cities: Minneapolis, St. Paul; Dallas, Fort Worth; Los Angeles; Seattle; and San Francisco. Community reaction to TCAS was excellent. Also, valuable operational data were collected as TCAS made approaches to airports in those cities. For example, varying terrain heights in Seattle, around the airport, foiled the intruder on ground detection logic. Analysts at the Center studied the data tapes (mailed back after every flight) and determined a parameter change which could accommodate terrain variations of up to 400 feet. Furthermore, by tabulating the traffic advisory data, the numbers and types of advisories one could expect (on the average) at each location is determined; i.e., in Philadephia, expect roughly 2 traffic advisories/approach and in Dallas, Fort Worth, expect 2.3 advisories per approach; expect 1 resolution advisory every 5.25 hours (approximately).

A study was made wherein the effectiveness of the antenna configuration, i.e., directional top and omnidirectional bottom, was determined. In 63 hours of flying approaches and en route to the destination cities, the bearing presentation was invalid on average of 5.4 percent of the total advisory time.

Dry run certification tests including ramp and flight tests were conducted in anticipation of supporting the airworthiness certification of Minimum TCAS II in a Piedmont B-727.

In conclusion, the TCAS II industry prototype is currently considered an acceptable system which can provide a valuable service to airline pilots through its ability to augment the air traffic control system. It is not in its final form however. Work needs to be done on the displays and on the rejection of nuisance alerts. The inservice evaluation of TCAS on a Piedmont B-727 is needed to provide the data necessary to bring Minimum TCAS II to its final form.

INTRODUCTION

PURPOSE.

The purpose of this report is to document the Federal Aviation Administration (FAA) Technical Center's test and evaluation activity of the prototype Minimum Traffic Alert and Collision Avoidance System (TCAS) II, SN01 and SN02, built by Dalmo Victor in Belmont, California.

OBJECTIVE.

The objective of this program was to perform a multipart evaluation of the TCAS II prototype in preparation for the 8-month inservice operational evaluation on Piedmont Airlines.

BACKGROUND.

TEST CHRONOLOGY. At the outset, a project plan was developed by the Guidance and Airborne Sytems Branch, ACT-140 (table 1, item 1). The project plan established a schedule for the completion of the testing:

Bench Tests P/O B727 Install	2 Weeks
B-727 Install and Checkout	2 Weeks
CAS Logic Evaluation	2 Weeks
Operational Evaluation	3 Weeks
National Tour	1 Week
Dry Run Certification Tests	As Necessary

SN01 TCAS was received at the Technical Center on May 7, 1983. The first 2 weeks went as planned. Then, during the first engineering flight test, an antenna failure and problems with the aircraft interfaces occurred which changed the test emphasis (see appendix E, item 2). After Dalmo Victor resolved the problems, testing proceeded per the project plan. Except for two additional delays due to problem resolution, the testing proceeded through the engineering tests into the operational evaluation.

During the first week of operational evaluation, as the third subject pilot was flying his encounter mission, several unexplained TCAS advisories were generated. The operational evaluation was temporarily halted while the Technical Center's Analysis Branch along with Dalmo Victor's analysts looked for the problem, which turned out to be a coding error. This was corrected at the factory. During this period, Technical Center TCAS personnel conducted an abbreviated surveillance analysis to identify tracking anomalies.

In August 1983, the TCAS II prototype was returned to Dalmo Victor for problem resolution and upgrade to the Piedmont Configuration. This was mainly the addition of interfaces and display drivers for the avionics in the Piedmont B-727.

While SN01 was at the factory, SN02 was being readied for evaluation. In September 1983, an acceptance test was conducted satisfactorily and SN02 was shipped to the Technical Center along with the Piedmont weather radar display, symbol generator, and control panel.

Serial No. 2 TCAS was shipped with extensive changes in software resulting from the upgrade to the Piedmont configuration and problem resolution. In order to properly verify all the changes, the engineering evaluation was repeated, to be followed by an operational evaluation and national tour. The engineering evaluation lasted from October 3 - 19, 1983, culminating in a 2-day review at the Center (see appendix E, item 32).

A week later, a subject pilot operational evaluation was started. Several consecutive failures caused concern about the reliability of the prototype system. Even so, only 1 day of flying was lost because the on-site support by Dalmo Victor was excellent. The operational evaluation was completed and the results were presented in a 2-day review at the Center. (See appendix E, items 13 to 17, and 36.)

The national tour was conducted from December 6 - 15, 1983. Upon returning to the Technical Center, TCAS personnel in coordination with Lincoln Laboratory began investigation of two problems documented in the operational evaluation review: (1) TCAS bearing jump, and (2) poor tracking on the Center's test aircraft used as targets in the planned encounter flights.

In April 1984, dry run certification tests were conducted to keep Technical Center flight crews briefed and ready for anticipated certification support.

Figure 1 chronologically reviews TCAS test activities described in this report.

PROGRAM COORDINATION. This section contains a list of organizations that participated during the various phases of this evaluation program.

Organization	Function	Evaluation Phase
FAA Technical Center, ACT-140	TCAS Project Group	All Phases
FAA Technical Center, ACT-230	Analysis Branch, CAS Simulation	Engineering Analysis
FAA Technical Center, ACT-600	Nike Radar Tracking	Engineering Operational Evaluation
FAA Technical Center, ACT-600	Aircraft Support	All Phases
FAA Technical Center, ACT-600	Terminal Radar Approach Tracking (TATF)	Operational Evaluation
FAA Technical Center, ACT-8	Video Production	Operational Evaluation
FAA Washington, APM-330	TCAS Program Office	All Phases
FAA NY Air Route Traffic Control Center (ARTCC)	Control of the Atlantic	Local Flights
FAA Atlantic City Tower and Approach Control	Control of Atlantic City	Local Flights
FAA NY Common Instrument Flight Rule (IFR)	Kennedy and Newark Control	Engineering Operational Tests
FAA Philadelphia Approach Control	Philadelphia area Control	Engineering Operational Tests
FAA Washington ARTCC	Washington area control	Engineering Operational Tests
FAA Atlanta Terminal Area Test Facility (TRACON)	Area control	Engineering Operational Test

Month	1 . . . . 8 . . . . 15 . . . . 22 29	
MAY 1983	TCAS SN01 Delivery; Bench Tests; A/C Install; Engineering Flight Test-SN01, Using SN01 & SN02 Antennas	To June 1, 1983
JUNE	Return SN01 to Dalmo Victor; Engineering Flight Test - SN01; TCAS Demo for Op Eval Working Group	
JULY	Engineering Flight Test-(SN01); Op-Eval Dry Run Encounters and Approaches; Op Eval-Part I; Surveillance Analysis-Ground Checks	To August 6, 1983
AUGUST	Surv. Analysis Flight Checks; Return SN01 to Dalmo Victor Move TCAS Instal. from N-78 to N-40; ATP on SN02	To September 1, 1983
SEPTEMBER	Repeat ATP SN02	
OCTOBER	Engineering Evaluation SN02; Engrng Review; Return SN02 to DV; Limited ATP	
NOVEMBER	SN02 to FAA; Op Eval Dry Run; Operational Evaluation - Part 2	
DECEMBER	Op Eval Review; National Demonstration Tour	To January 1, 1984
JAN 1984	Investigate Bearing, Tracking Problems; Travel to Dalmo Victor Problem Analysis; Antenna Pattern Measurements	To February 6, 1984
FEBRUARY	Acceptance Test on SN01 and SN02 TCAS; Ship SN01 to FAA Technical Center; Antenna Stress Tests; Ship SN01 TCAS and SN06 Antenna to Piedmont	
MARCH	Install SN04 Antenna on N-40; Antenna Evaluation; Piedmont observer Training Flights (SN02 TCAS)	

Month	1 . . . . 8 . . . . 15 . . . . 22 29	
APRIL	ATP on SN01 and SN02; Dry-Run Certification; Demo Flight	To May 7, 1984
MAY	Bench Tests while N-40 Down for Engine Change	
JUNE	Dry-Run Certification	
JULY		

FIGURE . TIME LINE OF TCAS TEST ACTIVITY

Organization	Function	Evaluation Phase
FAA Minneapolis/St. Paul Approach Control	Area Control	National Tour
FAA Dallas/Fort Worth Approach Control	Area Control	National Tour
FAA Los Angeles TRACON	Area Control	National Tour
FAA Burbank Tower	Area Control	National Tour
FAA Seattle Approach Control for SEATAC Airport	Area Control	National Tour
FAA Bay TRACON	Area Control	National Tour
FAA San Francisco Int'l Tower for Oakland and SFO Airports	Area Control	National Tour
ARINC Research Corp.	Coordination of Piedmont Progam	Certification Tests
Boeing Aircraft Corp.	Subject Pilot Data Forms	Operational Evaluation
Dalmo Victor Div. TEXRON	TCAS Manufacturer	All Phases
MIT Lincoln Lab	Surveillance and Operational Test Design	Engineering Operational Tests
Teledyne Avionics	IVSI Manufacturer	All Phases
Military FASFAC VACAPES	Oceana, Va. for W107 and W108	Engineering Operational Tests

MAJOR TESTING ACCOMPLISHED. The Technical Center project plan contained five major objectives to be accomplished in the evaluation program.

1. Verify the operation of the Dalmo Victor Prototype TCAS II.

2. Validate the cockpit display configuration and operational procedures for the minimum TCAS II.

3. Demonstrate minimum TCAS II as installed in a B-727 to the aviation community.

4. Reduce Piedmont's Supplemental Type Certification (STC) activity by conducting traceable tests in coordination with the Aircraft Certification Office (ACO) (Atlanta).

5. Develop training techniques for Piedmont (Phase II) and future air carrier evaluations.

The scope of objective 1 included the validation of the CAS logic supplied by The MITRE Corporation and implemented by Dalmo Victor, verification of the aircraft interfaces, and verification of the TCAS displays. The CAS logic validation was accomplished through the engineering evaluation of the TCAS prototype, and through computer simulation, at Dalmo Victor, of approximately 1,100 scenarios supplied by the Technical Center's Analysis Branch. Dalmo Victor's playback of these scenarios helped to locate problems in CAS logic implementation that went undetected in the engineering evalution. Validation of the aircraft interfaces and TCAS displays were also part of the engineering evaluation.

Although the original scope of the engineering evaluation was limited to the three areas just described, additional testing was added as the necessity arose. Surveillance subsystem testing was conducted. Specifically, non-Mode C track formation and extension, image rejection (e.g., multipath), and track update probabilities were studied in varying aircraft density conditions.

As part of the surveillance subsystem testing, ACT-140 developed techniques to make antenna transmit and receive patterns and gain measurements. These tests were designed to be conducted air-to-air or on the ramp, using the TCAS test van. These tests were mandated when poor angle of arrival (AOA) performance and aircraft tracking was observed and the routine test and analysis of the radio frequency (RF) stages showed no failures.

Objective 2 was accomplished in the Center's operational evaluation. Initially, 12 subject pilots were scheduled to participate. After the evaluation commenced, an additional subject pilot was invited to participate.

Two of the major efforts of the operational evaluation were the development of a training package (see objective 5) and questionnaires for pilot evaluation data collection. Both efforts were accomplished at the Technical Center in coordination with the Washington Program Office, Arinc Research Corporation, and the Massachusetts Institute of Technology's Lincoln Laboratory.

Objective 3 was accomplished in the national demonstration tour.

Objective 4 was accomplished in dedicated dry run certification testing which drew on experience gained in the Technical Center's engineering and operational evaluations. The testing consisted of ramp and flight tests to measure electromagnetic and radio-frequency interference, TCAS bearing accuracy, and CAS logic performance.

Objective 5 was accomplished through the production of a training video tape and training package for the TCAS operational evaluation. A total of three versions of the video tape were produced at the Center spanning a period from May to July 1983. The final version of the tape will be used to train line pilots flying for Piedmont.

RELATED DOCUMENTATION.

ACT-140 documented the progress in the test program by means of summary reports, memoranda, and trouble reports. Summary reports were distributed after every flight (by sponsor's request) and contained detailed description of the day's events, preliminary results and observations from the flight, and a list of problems noted in flight.

When detailed analysis of the flight data was completed, any anomalies were reported by means of the trouble report system.

Throughout the program information was exchanged in memoranda, meeting digests, modifications to acceptance tests, and test reports.

Table 1 is a summary of all documents distributed by ACT-140 as a result of the test effort; appendix E contains a complete list of documents.

TABLE 1. SUMMARY OF TCAS DOCUMENTATION PRODUCED AT THE TECHNICAL CENTER IN SUPPORT OF THE PROTOTYPE EVALUATION

Document Type	Number Published	Topic	Appendix E Referenced
Test Plan	3	Test planning and conduct.	Page E-1, Nos. 1 thru 3
Summary Report	14	Each report contains informal results from a particular flight.	Pages E-1, E-2, Nos. 4 thru 17
Trip Reports	6	Factory acceptance test reports.	Page E-2, Nos. 18 thru 23
Information Memoranda	14	Short documents for quick dissemination of test results and/or related information.	Pages E-3, E-4, Nos. 24 thru 37
Letters	4	Communique to non-FAA organizations for quick dissemination of program information.	Pages E-4, E-5, Nos. 38 thru 41
Trouble Reports	57	A system for tracking noted problems in the TCAS prototype.	Page E-4, No. 42.

DISCUSSION - FACTORY TESTS

ACCEPTANCE TESTING AT DALMO VICTOR.

PURPOSE. The acceptance tests conducted at the factory were often an extension of the Technical Center's engineering evaluation in addition to determining government acceptance of the TCAS hardware. Usually, modifications were designed into Dalmo Victor's test plan to validate some problem resolution or exercise a particular TCAS function or subsystem.

BACKGROUND. Early tests were designed to test the surveillance subsystems including RF stages, reply processors (e.g., degarblers), and threat tracking software. Sections in the test plan also pertained to Mode S tracking and TCAS to TCAS coordination, but these procedures were not always performed.

In March 1983, the Technical Center's TCAS II prototype evaluation project plan was published, and contained sections which dramatically modified the scope of the acceptance test conduct to include a bench test of the CAS logic implemented in the prototype. The project plan listed 33 encounter scenarios which could be performed using FAA supplied target generators and RF apparatus. The project plan listed each scenario, along with expected performance criteria that the TCAS prototype should meet.

The performance criteria was developed on the Fast Time Encounter Generator, a model of CAS logic resident on the Center's Honeywell Computer. With these scenarios, comprehensive CAS logic testing could be performed at the factory with the TCAS logic designers present.

In subsequent acceptance tests, selected encounters were amplified slightly to test such parameters as intruder-on-ground detection and aircraft gear and flap sensing.

ACCEPTANCE TEST CONDUCT. Usually, an acceptance test was conducted after a significant change in either of the TCAS prototypes. Sometimes problem resolutions or design changes accounted for significant changes to the prototype software. In these cases, Technical Center project personnel issued a memorandum suggesting changes to the acceptance test plan in order to validate the design change or problem resolution (for example, refer to appendix E, item 9).

Before the acceptance test, three or four project members would assemble, divide responsibilities, and develop a proposed schedule for the completion of the tests. The proposed schedule was sent to Dalmo Victor for their approval.

The team then traveled to Dalmo and started the acceptance test in a meeting with their test engineers. Requirements for deliverables were presented, and a test schedule agreed upon.

As the tests progressed, one or two team members witnessed the activity in the laboratory, while the other team members examined data printouts either from previous tests or from Eclipse computer simulation. The team effort proved to be an efficient way to complete extensive testing in a short time.

Deliverables from acceptance tests included a document containing bound copies of the ATP data sheets and magnetic tape copies of the recorded Acceptance Test Plan (ATP) data. If the ATP was conducted to validate some problem resolution, "before and after" printouts of Eclipse computer simulation demonstrating correct TCAS response were also considered deliverables.

ACCEPTANCE TEST COMPLETION SCHEDULES. The dates of the factory acceptance tests are shown in the time line in figure 1.

ACCEPTANCE TEST DOCUMENTATION. Formal trip reports were prepared after each test (see appendix E, items 18 through 23).

DISCUSSION - TECHNICAL CENTER TESTS

AIRCRAFT INSTALLATION.

The installation of the Dalmo Victor TCAS on the FAA test aircraft, a Boeing 727 (N-78), took place during April 1983. As installed, the equipment was configured to operate in a testbed fashion, collecting data continuously throughout a test flight for purposes of system performance analysis. The installation in N-78 is described in table 2.

TABLE 2. TESTBED CONFIGURATION OF TCAS ON FAA AIRCRAFT N-78

Aircraft Interfaces

Gear - FAA installation replaced existing aircraft switch with a double pole double throw (DPDT) switch on the landing gear. Extra contacts complete isolation from aircraft systems resulting in no impact to aircraft operation for any TCAS failure.

Flaps - FAA installation used existing aircraft flaps switch which become active for flaps extension beyond 25° (active at 26°). TCAS input is diode isolated and fused. As a result, TCAS failure cannot affect aircraft systems.

Air/Ground Switch - FAA installation used existing switch which is DPDT. The extra contacts provide complete isolation and prevent impact to aircraft systems in the event of TCAS failure.

Mutual Supression - FAA installation is tied directly to mutual supression bus. A TCAS failure could result in lack of mutual supression which would cause a TCAS invalid indication against own ship's transponder. Due to alternating current (ac) coupling, no impact to air traffic control (ATC) radar tracking would occur.

Radar Altimeter and Status - FAA installation used direct connection to the altimeter analog output. The TCAS analog input was well isolated using 100 kilo-ohms resistence series with the TCAS sensing circuitry. The radar altimeter status input was diode isolated. Note: the radar altimeter has two status outputs; one goes inactive in the event of Built-in Test Equipment (BITE) failure, the other goes inactive in the event of overrange (altitudes above 2,500 feet). The BITE output must be used because TCAS defaults to an inactive state when the radar altimeter status input goes inactive.

Barometric Altitude - The FAA installation used the aircraft Mode C encoder outputs to provide aircraft barometric altitude. The TCAS inputs were diode isolated and fused.

Tape Recorder and Clock - An Ampex 9-track tape recorder and time code generator were interfaced to TCAS to provide time of day (TOD) and data recording.

TCAS Display - The Traffic display, aural alerts, and caution warning switch functions were all performed by the Airborne Intelligent Display (AID) built Lincoln Laboratory.

Aircraft Power - A power conditioner was installed in N-78 to provide continuous sag and transient-free power to the project installation. During flaps activation, all B-727's suffer severe power lags. In the FAA aircraft, primary voltage dropped from 115 volts to 40 volts for 0.2 seconds. Without the conditioner, the sag caused the AID to lose its operating software resident in volatile random access memory (ram).

In August 1983, the TCAS was removed from N-78 and moved to the second Technical Center B-727, tail number N-40. This installation was to be as close as possible to the installation planned for the Piedmont B-727. To this end, several changes were made to the configuration in N-78. These were mainly in the TCAS displays; N-40 employed display avionics supplied by Dalmo Victor, instead of the Airborne Intelligent Display (AID), to provide the display function. In addition, the power conditioner was removed from the installation because N-40 has a power distribution system similar to the Piedmont B-727. Table 3 lists the differences between thens installations on N-40 and the Piedmont aircraft.

The TCAS avionics include (see figures 2 and 3)

RF Unit - contained in an 8 MCU size chassis
Computer Unit - contained in a 6 MCU size chassis
Symbol Generator - contained in a 1/4 ATR size chassis
Recorder and Clock - FAA installation uses separate clock and 9-track tape recorder. Piedmont uses integrated clock and 9-track cartridge recorder.

ENGINEERING EVALUATION.

The TCAS prototype evaluation at the Technical Center consisted of three parts:

1. Bench tests
2. Static (ramp) tests
3. Flight tests

BENCH TESTS. Bench tests were conducted on SN01 and SN02 TCAS to measure critical transmitter parameters including maximum power output and whisper shout levels, frequency, and antenna voltage standing wave ratio (VSWR). Bench tests were also conducted to measure critical receiver parameters including sensitivity, variable minimum triggering level (VMTL) thresholds, and compression points. The performance of the AOA subsystem was examined using up to three RF inputs whose levels were adjusted to simulate the relative levels of signals received by the antenna. The test configurations and procedures for each of these tests is contained in a bench test plan (see table 1).

STATIC TESTS. Tests of the transmitter and receivers were repeated several times in order to determine system reliability and stability over an extended period.

Static tests were conducted to measure trasmit and receive antenna patterns and AOA accuracy. Transmit patterns were measured in 15° steps to determine if the TCAS whisper shout sequence was being correctly radiated in space. A van with a variable height antenna mast was parked over a survey point, 1700 feet from the TCAS aircraft. The van was equipped with a transponder (Bendix TRU-2B) and a blade antenna (type AT741) mounted on the mast. The raw video line on the transponder interface plug was tapped and routed to an oscilloscope in the van. Sweep synchronization for the oscilloscope was taken from the TCAS transmit pretrigger output (TPT) and transmitted over two wire twisted pair to the van. To prevent RF leakage, ferrite cores were located around the pair at both ends of the cable. The sync pulse was regenerated inside the van using a pulse generator.

TABLE 3. DIFFERENCES BETWEEN THE TCAS INSTALLATIONS ON FAA AN^ PIEDMONT AIRCRAFT

FAA Installation	Piedmont Installation
TCAS avionics installed in passenger compartment of the aircraft.	TCAS avionics installed in avionics bay of the aircraft.
Separate CRT for display of TCAS information. (Bendix cathrode ray tube (CRT for TCAS is not compatible with N-40's weather radar. TCAS information not displayed on ships radar display.)	Weather and TCAS information multiplexed on the same CRT.
Caution/Warning switches interfaced to TCAS unit via separate interface box. Note: FAA switches are hall-effect devices which require level shifting to match TCAS.	Mechanical caution warning switches directly compatible with TCAS unit.
Modified cabling to permit test flight configuration or to electrically simulate the Piedmont installation.	Interface cabling tailored for fixed installation.
Separate clock and 9-track (open reel) tape recorder.*	Integral clock and 9-track cartridge recorder.
Recorder operates continuously.	Recorder operates event-driven.

*The Piedmont integral clock and 9-track recorder was installed ta recorder method to use seperate clock tested on N-40, however, the primary da and 9-track recorder.

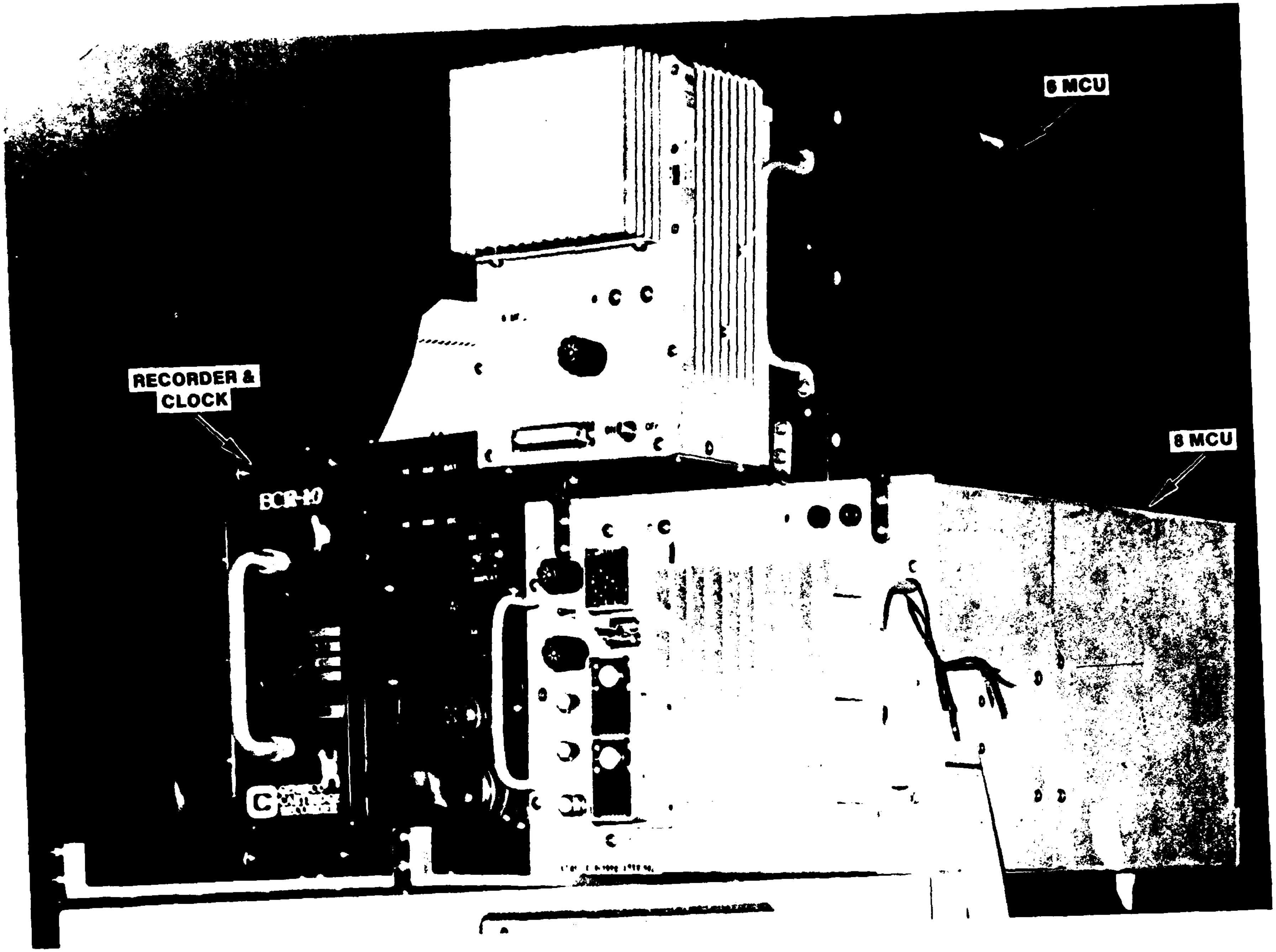


FIGURE 2. TCAS AVIONICS AND RECORDER/CLOCK

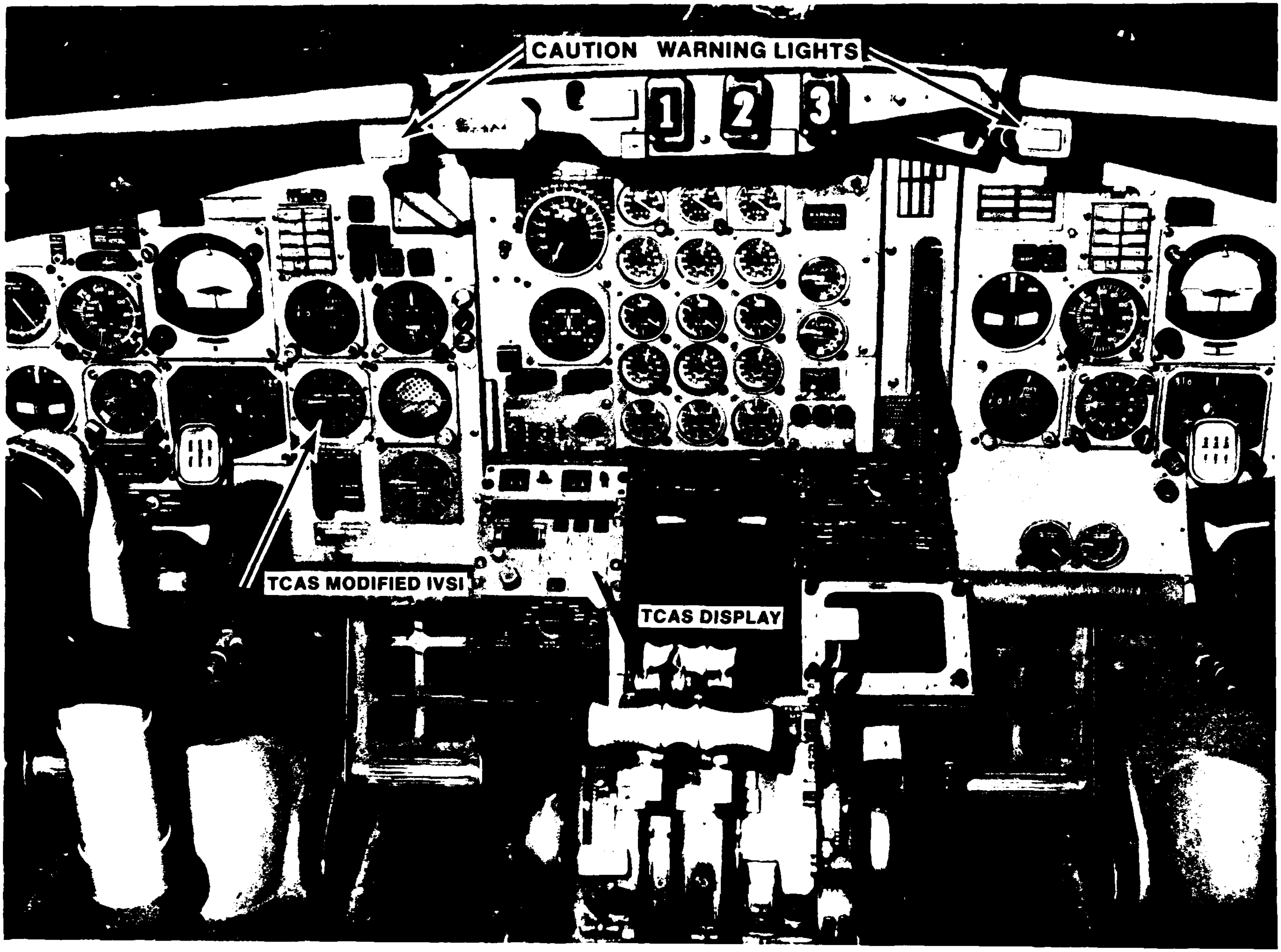


FIGURE 3. COCKPIT INSTALLATION - TCAS DISPLAYS

The TCAS aircraft was parked over a compass rose (figure 4) and rotated 30° in 15° segments. All the pulses in the whisper shout steps in the forward and lateral directions were measured for relative amplitude, pulse width, and shape.

Antenna received patterns were measured using a somewhat different technique. A test transponder (TRU-2B) was located in the TCAS laboratory in the Flight Operations Building (FOB 301). A high directional yagi antenna with a ±6° vertical beamwidth was located on the roof of FOB 301 positioned such that ground multipath radiation would be blocked. The TCAS equipped aircraft was parked at the end of runway 8 and rotated 360° in 15° increments illuminated by the yagi. At each location, eight measurements were made, including RF level and video level of each of the four antenna ports. The results of this test are two plots of antenna patterns; one plot with the antenna ports terminated into 50 ohms and one plot with each antenna port terminated in the appropriate receiver for the port. With this technique, receiver effects on AOA performance are readily identifiable when the plots made with and without the receivers are compared.

FLIGHT TESTS. The flight test portion was by far the most substantive portion of the engineering evaluation. Virtually every TCAS subsystem was exercised and evaluated. The various subsystem tests are described below.

CAS Validation. The collision avoidance logic performs threat detection and computes projected intruder and TCAS paths to provide advisory or escape information to the pilots. This subsystem was tested in three parts: (1) in bench testing which was part of the factory acceptance tests; (2) in encounter Flights at the Technical Center; and (3) in the approach missions flown during the engineering evaluation, operational evaluation, and national tour.

Encounter Flight Testing. Eighteen encounter scenarios were selected and flown at the Technical Center (appendix C). These scenarios were designed to exercise the major logic functions which could not be tested on the bench. As the evaluation program progressed, new scenarios were added to test more specific logic functions (see table 4).

All advisories generated during the encounter missions were analyzed, including those generated during the aircraft calibration. Aircraft calibration involves close proximity, slow, or zero closing rates and continuously variable altitudes. These conditions exercise logic paths which are difficult to access in typical encounter runs.

Approach Missions. Each time an approach mission was made to a city, the flight data was reviewed. The CAS analysis consisted of extracting all the traffic and resolution advisory data and examining the logic paths used in generating the advisory. Table 4 shows the criteria used to evaluate the logic performance.

Modification of the CAS Validation. After the beginning of the logic evaluation, two areas required modification: (1) bench test conduct and (2) encounter flight test conduct.

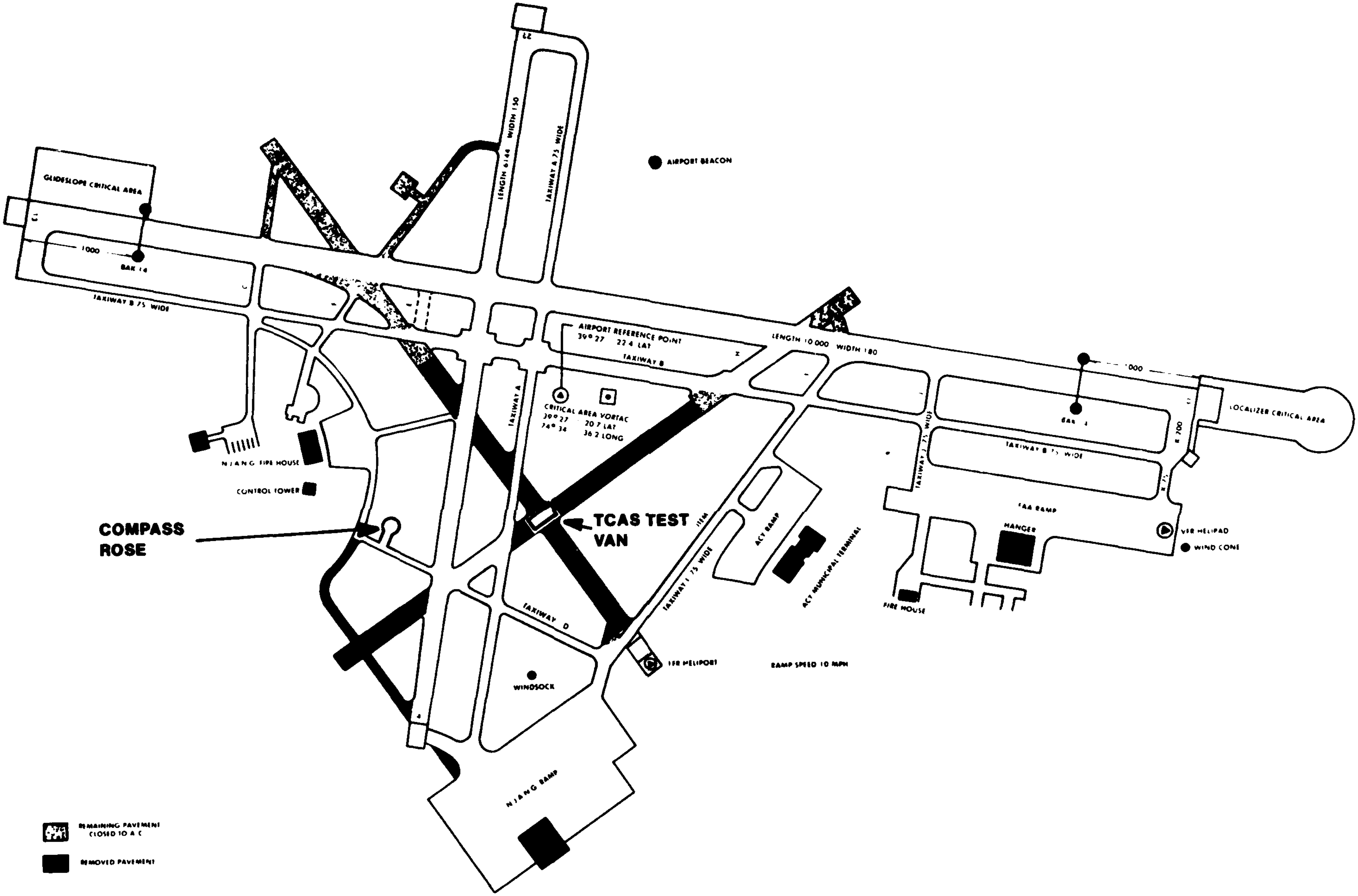


FIGURE 4. TECHNICAL CENTER/ATLANTIC CITY AIRPORT, NEW JERSEY

TABLE 4. CAS LOGIC EVALUATION SUMMARY

Logic Parameter	Logic Variables	Interpretative Analysis	Reference Appendix C Bench Test Encounter #	Reference Appendix C Flight Test Encoutner #	FTEG Validation
1. TCAS Sensitivity Level	G. Index, G. Layer	Observe TCAS alarm thresholds, protection volumes, etc., change vs altitude	1,5.6	Profiles 1,2,15 29,30	All encounters
2. Intruder Tracking a. Surveillance-CAS Interface b. Range & Altitude Tracking c. Mode C Credibility d. Multipath & false track elimination		Verify TCAS's ability to correctly initiate and maintain a CAS track whether target reports are received each cycle by surveillance or not.	7,8,9,11,16, 19	Profiles 5,3,12, 13,20,26,27	
3. Threat Detection -Range & Altitude Tests -CAS Establishment Criteria	TAUR, TAUV, TAUMOD, EHTR, ALIM	Primarily, the analysis was intended to insure adequate wanring time for intruders who violated the protection volume Pop-up targets were also tested.	all	Profiles 12,13,20	
4. RA Selection a. Positive b. Negative c. Projection & Modeling d. Critical Interval e. Multipath Aircraft f. TCAS Abort	ALIM, ZTHR, ZDGOAL, ZBGOUNDS, N.ZDNER, B,ZDITYER	Evaluate sense selection and strength based on encounters geometry. In altitude rate encounters, check RA sense if *modeled escape exceeds* intruder bounds.	8,9,10,11,16 17,18,28	Profiles 1,2,3,4,5 9,10,13,16,19,20,21 22,23,24,25	
5. Firmness Test a. RA delayed due to low firmness b. *RA selected despite* low firmness c. Advisory strength modified by firmness	N.CASFIRM, N.DZINER, B,ZDIYTER	Verify sense selection when firmness is low. TCAS either picks the sense despite low firmness or delays a period of several seconds until firmness increases.	16,17,18,19 21,23,30,31 32,33	Profiles 18, 19,20 26,27	
6. Advisory Inhibit a. Intruder on ground b. Ground Proximity c. Inhibit climb at extreme altitudes d. Non-Mode C>15,500' e. TCAS "Dirty"	ITF, IOGROUN	Fly scenarios testing the various thresholds and observe proper TCAS response.	3,6,7,27 Note a scenario was added to test IFT, IOGROUN as of January 1984	Profiles 28,29,30 Approaches	

Senarios for the bench and encounter tests were suggested by the MITRE Corporation as those necessary to properly exercise all the logic paths. The Technical Center's Analysis Branch also suggested several scenarios. ACT-140 test personnel met with MITRE, the Analysis Branch, and APM-330 to develop bench and flight test strategies.

As the engineering evaluation progressed, logic errors forced project analysts to realize that the early conclusions were no longer valid. Encounter scenarios were added to the flight test program, and the Center's target generator (used in the bench tests) was modified to supply grey code on a plug directly compatible with the TCAS prototype. The target generator is capable of generating ascents or descents from 0 to 6000 feet per minute.

Aircraft Interfaces Validation. The aircraft interfaces of the Piedmont configuration were verified in flight testing. The methodology included two observers, one in the cockpit and one in the cabin. The cockpit observer called out event marks over the ship's intercom, and the cabin observer would record the time of the mark using the TCAS system clock. Variations in the time of the recorded event and actual event were less than 1 second, which yielded adequate measurement accuracy considering the 1-second TCAS update rate.

The following paragraphs describe the interfaces and their test conditions:

1. Radar Altimeter and Status. After takeoff, while climbing out, the cockpit observer calls out marks every 500 feet from 0 feet to 3000 feet above ground level. The cockpit observer used the radar altitude gauge from 0 to 2500 feet marks and the pressure altitude gauge for the 3000 foot mark. The cabin observer recorded the time of the mark, and the direct current (dc) voltage on the radar altimeter input at the mark. This process was repeated in reverse order on landings.

TCAS response to the radar altimeter status line was verified by causing a built in test equipment (BITE) failure of the altimeter.

2. Gear and Flap Sensing. The cockpit observer called out "gear down and locked" and "flaps past 30" to indicate the landing configuration on approaches, and "gear up" and "flaps up" on departures.

3. Pressure Altitude. After a flight, the data printouts were scanned for own aircraft altitude behavior. Missing codes or jumps of 200 feet or more were considered fault conditions. During each flight, the flight personel spot checked the altitude indication on the Tektronix performance monitor each time the pilot reported his altitude to air traffic control (ATC).

4. Air/Ground Switch. This interface was verfied by the performance level change as the aircraft left the ground.

5. Weather Radar Status Input. TCAS response to the BITE status line was not tested in flight, but was verified during the factory acceptance test.

6. Mutual Suppression. This line was continuously monitored by flight test personnel as one trace on a dual trace oscilloscope. The TCAS suppression pulses were monitored along with suppression from all other avionics on the bus. Test personnel watched for erratic timing, bus conflicts, or loss of signals.

7. Genisco Recorder (ECR-10). A flight consisting of approaches to Atlanta was made with the ECR-10 operating in the Piedmont configuration. (Note: In the Piedmont configuration, TCAS derives time of day from the ECR-10, thus checking both interfaces.)

Tracker Accuracy Validation. The accuracy of the intruder's range, altitude, and bearing, as determined by TCAS was measured via orbits. Orbits refer to a flight test where the test aircraft flys circles of 1 mile radius around N-40 at various relative altitudes (reference 1, table 5). Both aircraft are tracked by the Center's precision radars (Nike - Hercules). The precision radars provide the position reference information. This test shows total accuracy as a function of azimuth and elevation angle.

TCAS Validation in Terminal Operations (Approaches). These missions are so called because they consist of approaches to active runways at nearby airports (e.g., Philadelphia, Washington, New York), terminating in missed approach and departure procedures. Approaches are useful to execise TCAS in higher density and differing terrains, and to gather statistical data on numbers and types of TCAS advisories. Typically, four to six approaches were made per mission.

FLIGHT SUMMARY. A listing of the flights in the engineering evaluation, along with a digest of each flight, are shown below. Flights beginning in May and continuing through August were made with SN01 TCAS.

May 1983:

1. May 18, 12:22:00-14:15:00. This flight consisted of approches to Norfolk, VA. The mission was primarily a checkout of the TCAS intallation in N-78 (including aircraft interfaces) with a secondary purpose of gathering non-Mode C tracking data and advisory rates against targets of opportunity.

2. May 24, 10:57:21-11:58:00. This flight consisted of orbits and encounters with two objectives: (a) verify the corrections made by ACT-140 as a result of the May 18 flight, and (b) to fly some representative encounter types to verify the flight test procedure including coordination with the chase aircraft, ground radar tracking, etc. Antenna failures forced the mission to be aborted.

3. May 25, 09:10:48-09:38:53. Due to successive antenna self-test failures on May 18 and May 24, the SN01 antenna was replaced with SN02. The morning flight was a short flight between the altitudes of 5000 and 15000 feet to establish the antenna performance.

4. May 25, 10:43:25-12:54:00. The morning flight was successful so an afternoon flight was made with two objectives: (a) perform limited AOA accuracy testing to ensure that SN02 antenna performed well enough to continue TCAS evaluation, and (b) begin the CAS logic evaluation. The afternoon flight was the formal beginning of the engineering evalution. Nine out of the planned 18 encounters were completed.

5. May 27, 10:03:24-11:18:55. This flight was intended to complete the remaining nine encounters in the CAS logic evaluation. An inflight altitude interface problem forced an attempt to use a test box to artifically generate own ship altitude for TCAS. This plan was unsuccessful and the flight was aborted.

June 1983:

6. June 15, 12:10:00-12:42:00. This was a short flight to verify SN01 antenna after failure resolution at Dalmo Victor. However, the antenna demonstrated the same failure as in the May 24 flights. Therefore, the problem was not resolved. This failure only occured at altitudes above approximately 2500 feet.

7. June 16, 10:10:19-12:42:33. For this flight, antenna SN01 was again replaced with SN02.

The TCAS prototype was returned to Dalmo Victor at the end of May for problem resolution, mostly in the aircraft interface sensing. Due to changes in the program requirements, some of the CAS logic was also changed. Therefore, the decision was made to repeat the CAS evaluation. Today's flight plan consisted of 18 encounters, 9 were completed. After the encounters a short accuracy analysis sequence and three approaches were made to Atlantic City Airport (runway 31) to verify interface problem resolutions. Precision radar tracking was requested for this flight.

8. June 16, 10:44:00-13:26:00. Because antenna SN01 was the primary antenna, ACT-140 project personnel were hesitant to perform extensive accuracy analysis on SN02 which was currently installed. However, SN01 was exhibiting self-test failures at altitude and Dalmo Victor was unable to locate the problem in their environmental chamber tests. Therefore, SN02 was designated the primary antenna. Today's test was an accuracy analysis consisting of orbits by the Convair aircraft.

9. June 24, 10:19:19-12:45:11. This flight was a continuation of the CAS logic evaluation where two and three aircraft encounters were flown. A total of 14 of the 18 encounters were completed.

10. June 28, 12:41:40-14:24:00. This flight was a demonstration flight for the attendees of the operational evaluation working group meeting held at the Technical Center, June 27-28, 1983.

July 1983:

11. July 6, 09:26:17-16:03:40. This was a 1-day mission to Atlanta, GA, to test TCAS in medium density conditions. A secondary purpose was to check TCAS multipath rejection logic.

12. July 7, 9:53:00-14:10:25. This was a 1-day mission to JFK Airport in New York to test TCAS in medium density.

13. July 13, 12:15:38-14:18:30. This was a dress rehersal for the first mission of the operational evaluation. The nine encounters listed in table 5 were completed.

TABLE 5. ENCOUNTER DESCRIPTIONS FORM OPERATIONAL EVALUATION - PART I

Encounter No. 1. Outbound from terminal; the intruder approaches from between 10 to 11 o'clock and is below and climbing. ATC calls; intruder passes below.

Encounter No. 2. Flying en route. Subject sees a coaltitude tail chase. ATC calls traffic.

Encounter No. 3. Nonstandard (teardrop) turn to fly inbound. After turn subject sees a head-on encounter. ATC calls.

Encounter No. 4. Climbing out from takeoff, overtaking an intruder who is visible above and to the side, but far enough away so that no TA or RA is generated. ATC calls traffic. To see traffic on AID, pilot must use "tracks" switch.

Encounter No. 5. Flying outbound but still in terminal; receive a TA on a GA non-Mode C (Aero Commander) who is climbing. The CV-580 will be in vicinity of GA but not close enough to generate a threat. ATC calls traffic.

Encounter No. 6. Flying en route. The CV-580 generates a 90° encounter, ATC calls traffic.

Encounter No. 7. Descending into a terminal area. Receive a climb RA; TCAS is overtaking a slower aircraft. ATC calls.

Encounter No. 8. Just before 90° turn onto final, receive a climb command from intruder; ignore the command because the turn onto final eliminates the threat.

Encounter No. 9. Execute a missed approach; upon climbing out receive a climb command from intruder underneath climbing.

August 1983:

14. August 9, 10:30:00-12:36:00. This flight consisted of orbits and encounters and was intended to validate the performance of SN05 antenna. SN05 antenna was a replacement for SN02 which had been used throughout the engineering tests and into the operational evaluation. Suspected degradation in SN02 (indicated by nonsymmetrical acquisition ranges versus azimuth) prompted the change.

15. August 11, 10:01:00-12:29:56. This flight was a 1-day mission to Washington National Airport to gather density data for Mode C and non-Mode C equipped aircraft.

September 1983:

No flights were conducted.

October 1983:

Flights beginning in October and continuing through November were made with SN02 TCAS.

16. October 3, 14:15:00-15:17:00. This was a short flight to test the changes in the aircraft interface sensing including the radio altimeter status flag and landing gear switch.

17. October 4, 10:00:20-14:17:40. This flight was a mission to Lincoln Laboratory to gather baseline data on SN05 antenna performance.

18. October 7, 14:36:10-16:03:47. This flight consisted of two orbits to check AOA accuracy, encounters to check acquisition range of the antenna and surveillance subsystem, and a low altitude multipath test to check image rejection.

19. October 11. This flight was a 2-day trip to Atlanta, GA, whose objectives were: (a) test high altitude antenna performance, (b) to exercise the Piedmont recording system, (c) test the intruder on ground logic, and (d) evaluate TCAS in medium to high density.

20. October 14, 10:24:20-11:31:05. This was an encounter mission to validate the CAS logic. A magnetic tape recorder interface problem forced the mission to be aborted.

21. October 17, 09:55:50-12:17:29. This flight was a repeat of the October 14 flight after the recorder interface was repaired by Dalmo Victor. A total of 14 out of 18 encounters were completed.

22. October 18, 09:45:10-13:38:50 The flight on October 17 was successful but some of the encounters involving vertical rates were not completed exactly per the test plan. These encounters, 5 through 15, were done again. After the encounters, a series of approaches were made to the Philadelphia International Airport.

November 1983:

23. November 21, 09:52:04-13:49:11. This flight was a formal AOA accuracy analysis. A formal AOA evaluation had not previously been completed on SN02 TCAS due to conflicting schedules for the operational evaluation and test range, and errors in the AOA processing circuitry. The problems in the AOA processor had been resolved and this flight was intended to be a formal accuracy analysis.

OPERATIONAL EVALUATION.

TCAS DISPLAY CONFIGURATION. The cockpit configuration in N-40 included one modified IVSI, two weather radar displays, loudspeaker, two caution/warning lighted switches, and TCAS control panel.

The IVSI was located in the primary instrument position and was tested and certified for use as the aircraft vertical speed indicator in the left position. The IVSI was modified to indicate resolution advisories with the addition of red climb and descend arrows and amber segments to indicate vertical speed limit advisories.

Two weather radar displays were employed. One was dedicated to the ship's weather radar system and the other dedicated to the TCAS. Normally, TCAS would multiplex with the radar, but in the FAA installation the two systems were not compatible. Both radar displays were mounted at the top of the center pedestal with the TCAS display in the primary position.

The TCAS control panel was located at the upper right corner of the weather radar display. Caution/Warning lighted switches were located underneath the glare shield at the pilot and copilot positions. The loudspeaker was located in the pilot's map and chart holder on the floor at the left of the seat.

Figure 3 shows the location of the TCAS display elements in the cockpit.

TCAS advisories were presented as follows:

Advisory Type	Aural	Presentation
Traffic Advisory	2 sec "c" chord; followed by spoken "Traffic"	Amber target symbol on radar display
Resolution Advisory Climb	2 sec European siren followed by repeatedly spoken "Climb"	Red target symbol; red IVSI "up"
Descend	European siren followed by by repeatedly spoken "Descend" arrow	Red Target symbol; red IVSI "down"
Don't Climb	European siren followed by repeatedly spoken "Don't Climb"	Red target symbol; all upper IVSI segments lit
Don't Climb	European siren followed by repeatedly spoken "Don't Climb"	Red target symbol; all upper IVSI segments lit
Don't Descend	European siren followed by repeatedly spoken "Don't Descend"	Red target symbol; all lower IVSI segments lit
Don't Climb/ Don't Descend	European siren followed by repeatedly spoken "Maintain Present Altitude"	Red target symbol; all IVSI segments lit
Limit Climb to 500, 1000, 2000 feet per minute (fpm)	European siren followed by repeatedly spoken "Limit Climb"	Red target symbol; all upper segments lit except corresponding speed limit
Limit Descend to 500, 1000, 2000 fpm	European siren Followed by repeatedly spoken "Limit Descent"	Red target symbol; all lower segments lit except corresponding speed limit
TCAS Abort	European siren followed by repeatedly spoken "TCAS Abort"	Red target symbol; red IVSI arrows

The TCAS caution/warning switches illuminated red for RA or amber for TA. The light was extinguished and associated aural alert cancelled by pushing the switch.

TEST CONDUCT. The operational evaluation was separated into two parts. The first part involved one flight (two subject pilots) and was accomplished per the project plan (appendix E, item 1, pp 4.1.2). The plan called for each subject pilot to experience nine encounters in an encounter mission, and then to fly a series of approaches into an airport at a major city (e.g., Philadelphia). A description of the encounters is contained in table 5.

The delineation between parts 1 and 2 of the operational evaluation occurred when SN01 TCAS was returned to Dalmo Victor for problem resolution and SN02 TCAS was returned to the Technical Center in September 1983. As a result of the experienced gained in part 1, changes, listed below, were made in part 2.

1. In part 1, the ATC function was provided by an air traffic controller in the Technical Center's TATF facility. In part 2, the ATC function was provided by the safety pilot. The delegation of ATC responsibility to the safety pilot made much closer maneuvers possible resulting in more numerous positive RA's compared to part 1.

2. In part 2, the number of encounters per subject pilot decreased. From the nine profiles used in part 1, six were deleted and three were added. The profiles used in part 2 are shown in appendix C.

Two other changes also were made in the program: (a) in part 1, N-78 was used; N-40 was used in part 2; and (b) in part 1 the cockpit displays were driven by the Lincoln Laboratory AID, in part 2 the displays were driven from the TCAS prototype and symbol generator. The AID driven weather radar display showed slightly different symbology than the prototype display. The differences were:

AID	Prototype
2-mile solid white range ring	2-mile range ring formed by 12 blue astrisks at the o'clock positions
Proximity targets in white	Proximity targets in blue
Deoverlap targets by movable tags	Deoverlap targets by symbol blanking
Aurals - female voice	Aurals - male voice

The test conduct of the program remained the same through the two parts. Subject pilots were invited to the Technical Center in pairs. Typically, they arrived the day before their scheduled mission, received training in the form of a slide presentation and video tape, and completed either 1 or 2 days of flying, depending on their schedule. From July until the November 15 mission, the training was provided by ACT-140 personnel. The November 17 to 30 missions, training was provided by ARINC personnel.

Safety was of the utmost importance in the operational evaluation. Subject pilots who were unfamiliar with the aircraft (N-40) and the Atlantic City area participated in the TCAS evaluation. To ensure safety, an altitude separation of 300 feet and a lateral separation of 0.25 miles was maintained at closest point of approach (CPA) to the target aircraft.

The encounters were chosen to provide all possible advisory sequences except for the TCAS abort. As the operational evaluation progressed, several unplanned TCAS aborts were generated (which yielded valuable operational data), but safety was never compromised because the safety pilot assumed control of the aircraft when necessary.

SUBJECT PILOT TRAINING. Subject pilots who participated in the operational evaluation received 1 day of ground school training when they arrived at the Center. Approximately 6 weeks before their scheduled mission, each subject pilot received a training manual, supplied by the MITRE Corporation, to study before their arrival.

Every subject pilot received the same training regardless of their previous experience with TCAS. The training consisted of a briefing and video tape, followed by a question and answer period. The training was never conducted on the date of a flight in order to allow plenty of time for a relaxed session and discussion period.

The main points emphasized in the briefing were:

1. Program overview.

2. TCAS protection scheme, definition of the threat volume as a function of time.

3. Definition of the size of the protection volume as a function of altitude.

4. Definition of the types of advisories TCAS generates and causes for advisor inhibits.

5. Explanation of TCAS limitations.

6. Explanation of the TCAS displays, use of cathrode ray tube (CRT) color to prioritize threat severity.

7. Explanation of TCAS unit controls.

8. Explanation of TCAS operational procedures.

9. Explanation of cockpit duties (e.g., safety pilot and observer).

The briefing was followed by a 20-minute video type training presentation, then a question and answer period.

When the training was completed, the subject pilots were asked to complete a preflight questionnaire (appendix E, item 1) which compiled information regarding pilot experience, pilot expectation, and training.

After the operational evaluation began, the training program was modified slightly to place less emphasis on the mechanics of TCAS (e.g., time based system, performance change versus altitude, etc.), and place more emphasis on the TCAS displays, all procedures, and how to use them. The detailed information regarding the mechanics of TCAS was conveyed in a handout.

OBSERVER DUTIES. See pages 63 and 64.

FLIGHT SUMMARY. A listing of the flights in the operational evaluation along with a digest of each flight are shown below:

1. July 19, 20, 1983. Two subject pilots participated in 2 days of flying preceded by a day of training. On July 19 an encounter mission was scheduled, and on July 20 approaches were planned. Weather caused the schedule to be reversed so that approaches were flown on July 19 and encounters were flown on July 20.

2. July 20, 1983. One subject pilot participated in an encounter mission. The mission was aborted when an unexplained advisory was generated.

3. November 8, 1983. Two subject pilots participated in 1 day of flying preceded by a day of training. The encounter mission was completed on schedule but a TCAS failure forced the approach mission to be cancelled.

4. November 15, 1983. Two subject pilots participated in 1 day of flying preceded by a day of training. Weather cancelled the encounter mission and only approaches were flown.

5. November 17-18, 1983. Two subject pilots participated in 2 days of flying preceded by a day of training. Both the encounters and approaches missions were completed on schedule.

6. November 29, 1983. The two subject pilots who participated in this flight were postponed from a scheduled November 8 mission due to a TCAS failure. They had received training on November 7. They arrived November 28 and flew missions of encounters and approaches on the 29th.

7. November 30, 1983. Three subject pilots arrived at the Technical Center on November 29 and received training. The three subject pilots completed the encounter and approach missions.

On December 1 and 2, a 2-day review of the results of the operational evaluation was held at the Technical Center. A digest of the review is contained in "Results - Technical Center Tests, Operational Evaluation" section of this report.

NATIONAL DEMONSTRATION TOUR.

The purpose of the tour was to demonstrate TCAS II to prospective users in the aviation community. In a round robin tour the TCAS equipped B-727 (N-40) visited cities where crew bases and domociles of major airlines and FAA certification offices were located. At each location, visitors were invited along to see the TCAS installation in the B-727. In addition, type-rated pilots from the host airlines were invited to fly several approaches to gain "hands-on" experience with the TCAS prototype.

In all, airports in five cities were visited: Minneapolis St. Paul (MSP), Dallas/Fort Worth (DFW), Los Angeles (LAX), Seattle (SEA), and San Francisco (SFO).

A digest of each flight is provided below:

1. MSP 12-7-83, 09:30 - 11:00. During this flight five approaches were made. Present were representatives from Republic Airlines, Northwest Orient Airlines, MSP Center; the regional office; television station KSTP; FAA ACE-160A, MAP-330, AFO-210; and ARINC Research Corporation. The flight passenger list totaled 16.

2. MSP 12:00 - 13:30. During this flight five approaches were made. This flight was attended by representatives from the organizations listed above except ACE-160A, and including the Cargill Corporation. The passenger list totaled 16.

The flight plan for both MSP flights was filed as Visual Flight Rules (VFR); approaches and 200 feet above ground level (AGL) and a 2000-foot pattern altitude. The weather was clear with visibility greater than 10 miles, winds 0-5 knots (kts), temperature 25°F.

3. DFW 12-8-83, 08:45 - 11:15. During this flight six approaches were made. The flight was attended by representatives from APM-330, ACE-160A, American Airlines, ARINC, Allied Pilots Association, ASW ACDO-33, DFW Airport (planning), and DFW (public relations). The passenger list totaled 16.

4. DFW 12:30 - 14:00. During this flight seven approaches were made. The flight was attended by the same organizations as the first flight. The passenger list totaled 21.

The flight plan for both DFW flights were filed as Instrument Flight Rule (IFR); approach to 200 feet then departure to a 3000-foot pattern altitude. The weather was clear with a high layer of clouds, visibility greater than 10 miles, winds light, temperatures in the 50's.

5. LAX 12-9-83, 12:25 - 14:55. During this flight six aproaches were made. The flight was attended by representatives from ACE-160A, APM-330, ANM-101L, ANA-173E, ANM-160L, ANM-130L, ANM-132L, ANM-2702, WP FSDO-62 (LAX), and FAA LAX TRACON. The passenger list totaled 17. The aproaches were not made to LAX due to bad weather. The approaches were made at Lindberg Field in San Diego.

One flight was made for TCAS demonstration. The flight plan was filed as IFR with 15000-foot cruise altitude from LAX to San Diego along airway V25, and return direct to LAX. In the San Diego Terminal Control Area (TCA), the flight plan called for approaches by departures to 2000 feet and back into the approach pattern. The weather this flight was clouds with heavy rain. Minimums were 500 feet, winds at 20-30 kts, and temperatures in the 50's.

6. LAX 12-10-83, 8:55 - 15:40. This flight was not a demonstration flight but was conducted to gather high density surveillance data in the Los Angeles Basin. The flight plan, described in detail in appendix E, item 6, consisted of a star shaped pattern around the Los Angeles Basin at 8000 feet in altitude.

7. SEA 12-12-83, 10:00 - 12:20. During this flight, eight approaches were made at Boeing Field. This flight was attended by representatives from ACE-160A, ANM-111, ANM-1305, ANM-1605, ANM-103N, APM-330, APM-330, Boeing Corporation, ARINC, and Alaska Airlines. Only one flight was made.

The flight plan for the SEA approaches was filed as IFR. The approach profile was terminated in a go around at 300 feet, followed by a departure to 4500 feet, and back into the pattern for the next approach.

The weather was heavy overcast above a 600-foot ceiling. The ceiling dropped steadily but the flight was completed before weather became a factor. Visibility was 2 to 3 miles in light mist, temperatures were in the 50's, winds were 5 to 15 knots.

8. SFO 12-13-83, 09:50 - 11:25. During this flight five approaches were made to SFO International Airport. Passengers on the flight included representations from: Atlanta Certification Office, United Airlines, ARINC, and Sperry-Dalmo Victor (Phoenix, AZ). The passenger list totaled 19. Two United Airlines pilots occupied the left seat and flew two approaches each.

The flight plan was filed IFR. The approach profile was termined at 200 feet in a go around, runway heading to 5000 feet, right turn back into the approach pattern. The weather was overcast with light rain and ceilings at approximately 1000 feet, winds 10 to 20 knots, temperatures in the 50's.

9. SFO 12-13-83, 13:35 - 15:45. During this flight four aproaches were made to Oakland (OAC) due to weather and increasing traffic load at SFO. The flight was attended by representatives from SFO tower, Atlantic Certification Office, ARINC, Dalmo Victor (Belmont, CA), and United Airlines (Denver). One pilot from Atlanta and one from United flew two aproaches each.

The flight plan was filed IFR. The approach procedure was the same as the SFO mission, but conducted at OAC. Weather conditions were similar to SFO.

10. SFO 12-13-83, 13:35 - 15:45. During this flight four aproaches were made to OAC due to weather and increasing traffic load at SFO. The flight was attended by representatives from SFO tower, Atlantic Certification Office, ARINC, Dalmo Victor (Belmont, CA), and United Airlines (Denver). One pilot from Atlanta and one from United flew two aproaches each.

The flight plan was filed IFR. The approach procedure was the same as the SFO mission, but conducted at OAC. Weather conditions were similar to SFO.

N-40 was outfitted with a signal source and target generator with the intention of having the capability to perform comprehensive testing on-the-road and to detect degradation in the TCAS prototype performance. By performing a series of tests between demonstration flights, proper TCAS operation was assured. The test fixture served a dual purpose in Minneapolis. In order to show the visitors TCAS operation, the flight technicians generated several simulated targets which caused traffic and resolution advisories. This was done while N-40 was taxiing.

Another technique was used during the tour to assure continued equipment performance. A standard transponder blade (AT741) was mounted on the aircraft fuselage, 3° right of top centerline, approximately 15 feet rear of the top TCAS antenna. The blade antenna was used as a monitor port to view the radiated TCAS interrogations, and was used as an injection port to transmit simulated aircraft replies from the target generator to the TCAS directional antenna. Thus, a rapid checkout of the entire TCAS was possible.

After each flight the data tapes, along with the flight logs, were mailed to the Technical Center where they were processed and analyzed.

DRY RUN CERTIFICATION TESTING.

A draft certification test plan was developed by the ARINC Research Corporation consisting of ramp and flight tests. ACT-140 followed the test plan by using generators and/or simulators from the Center's avionics shop to excite the aircraft communication and navigation systems, with and without power applied to TCAS. Each aircraft system was individually tested at the low, middle, and high points in its operating range to identify mutual interference which may occur over less than the system's operating range.

Each aircraft system was tested in the manner described above except the high frequency (HF) communication equipment. To test the HF, three local radio stations were tuned and used as excitation.

When the ramp test procedures were completed and adopted, the flight test portion of the certification test plan was designed. ARINC's certification test plan included a flight test section which outlined 33 encounter scenarios and the expected result of each scenario. Four of the scenarios involved two chase aircraft.

ACT-140 and ACT-630 coordinated to assign operating altitudes, position fixes, run intercept points, and speed and vector requirements for each encounter. The resultant encounter profiles are shown in appendix C.

Chase aircraft for the flight test were based at Hangar 6 in Washington. The primary aircraft used in all encounters was a Lockheed Jetstar (tail number N-1), and the second aircraft, used only in the three aircraft encounters, was a Cessna Citation (tail number N-2).

The copilot in the TCAS equipped B-727 also functioned as safety pilot and flight coordinator. His responsibility, aside from normal copilot duties, was to coordinate the chase aircraft for each run by providing run number and recommending "last minute" course changes to properly effect the encounter scenario.

Before the dry run certification flight there was a crew briefing wherein the flight profiles, verbal communications protocol, abort procedures, and position fixes were all briefed. After the flight an informal briefing was held to get pilot and crew reactions to the mission including relative success or failure and any observed problems.

DISCUSSION - FLIGHT DATA HANDLING

DATA REDUCTION AND ANALYSIS.

This section describes the processes developed at the Technical Center to reduce and display TCAS data.

DATA REDUCTION PREPARATION. The procedure for starting the recorded data through the data reduction system is shown on figure 5 (Processing #1). Data Reduction and Analysis (DR&A) acitvity begins after the test flight has been completed and the test crew has returned to the FAA with the recorded data.

Original data tapes are labeled and copied to backup tapes in order to safeguard the source recordings. Copy tapes are submitted to the data reduction specialist responsible for activating the processing function.

Once the data base files are allocated, a job submittal command language (JCL) stream for message processing is prepared. The JCL reflects all of the options selected by the project engineer for reducing the recorded data to listings, plots, and subfiles. The copy tapes are then delivered to the computer facility and the JCL is submitted for processing of the data.

MESSAGE PROCESSING. The procedure for message processing is shown on figure 5 (Processing #2).

The data tape is expanded from 16 to 36 bit Honeywell words and a data file is written to disk. This file becomes input to BELLPRO where the recorded data are deblocked and the various message types and plots are processed according to the options selected.

Upon completion of the BELLPRO run, a record of the options selected is printed on a summary sheet as part of standard end-of-job processing. In addition to the options printout, the summary sheet lists the number of physical blocks of data read from the input file, the number of each type of messages encountered, and the total number of messages identified as "lost messages."

There are several programs that process the data file as requested.
TEMPTRAN generates a Surveillance Coast Summary File, Coast Transition Matrix, and Coast Transition Probability Report.

TOTMSGZ accumulates by second the total number of zero and non-zero type messages as well as the total number of dropped mesages. Output is a second-by-second listing with a cumulative total.

BELLTA summarizes traffic advisories recorded in message type 10 and generates a report of these advisories and related information referenced by time.

MODECTR generates a listing of accumulative Mode C, non-Mode C, and reply reject counts as well as a quick-look plot with reference to time. A summary file is also generated to be plotted on the Tekronics 4054.

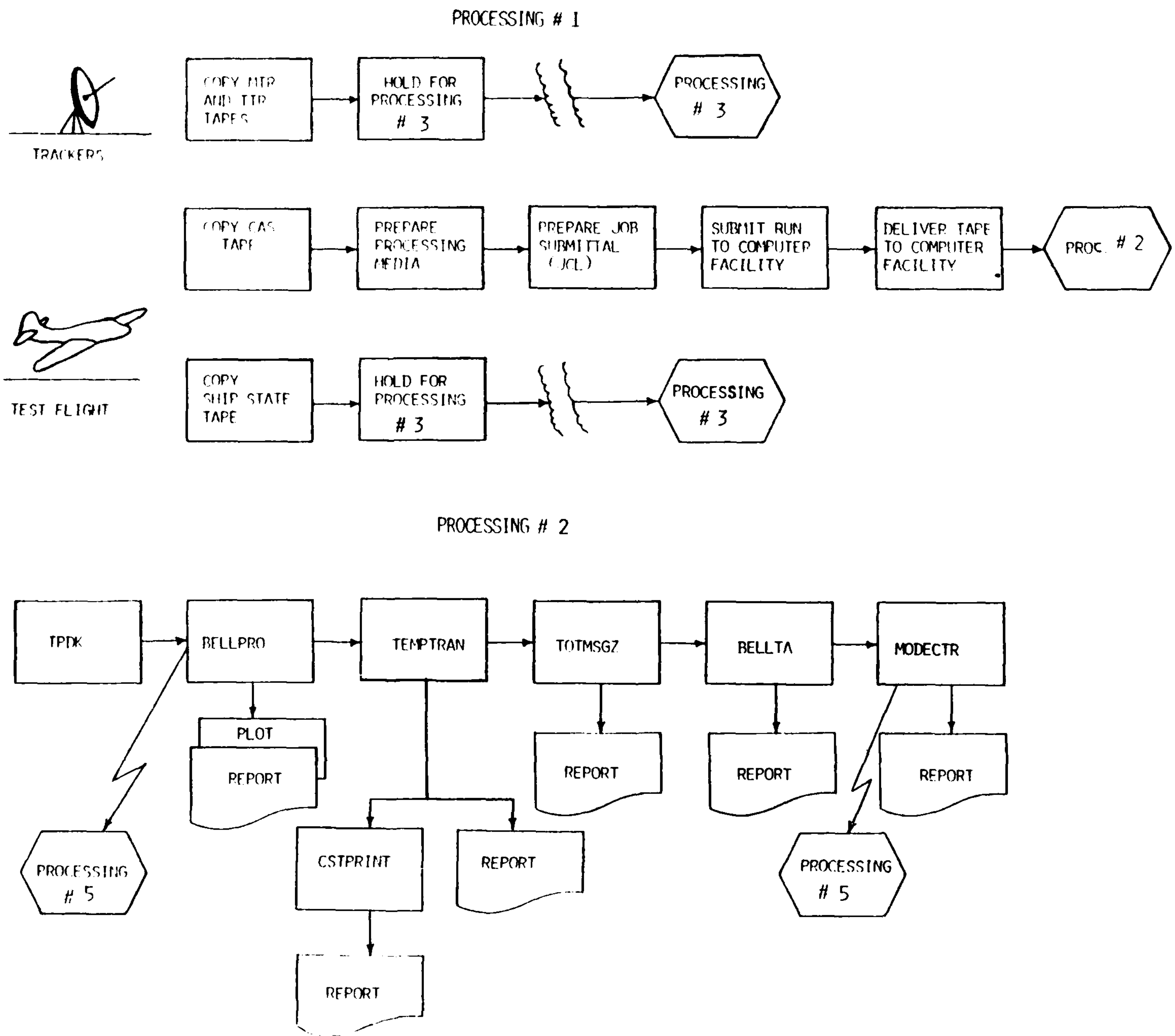


FIGURE 5. FLIGHT DATA REDUCTION FLOW CHART (SHEET 1 OF 2)

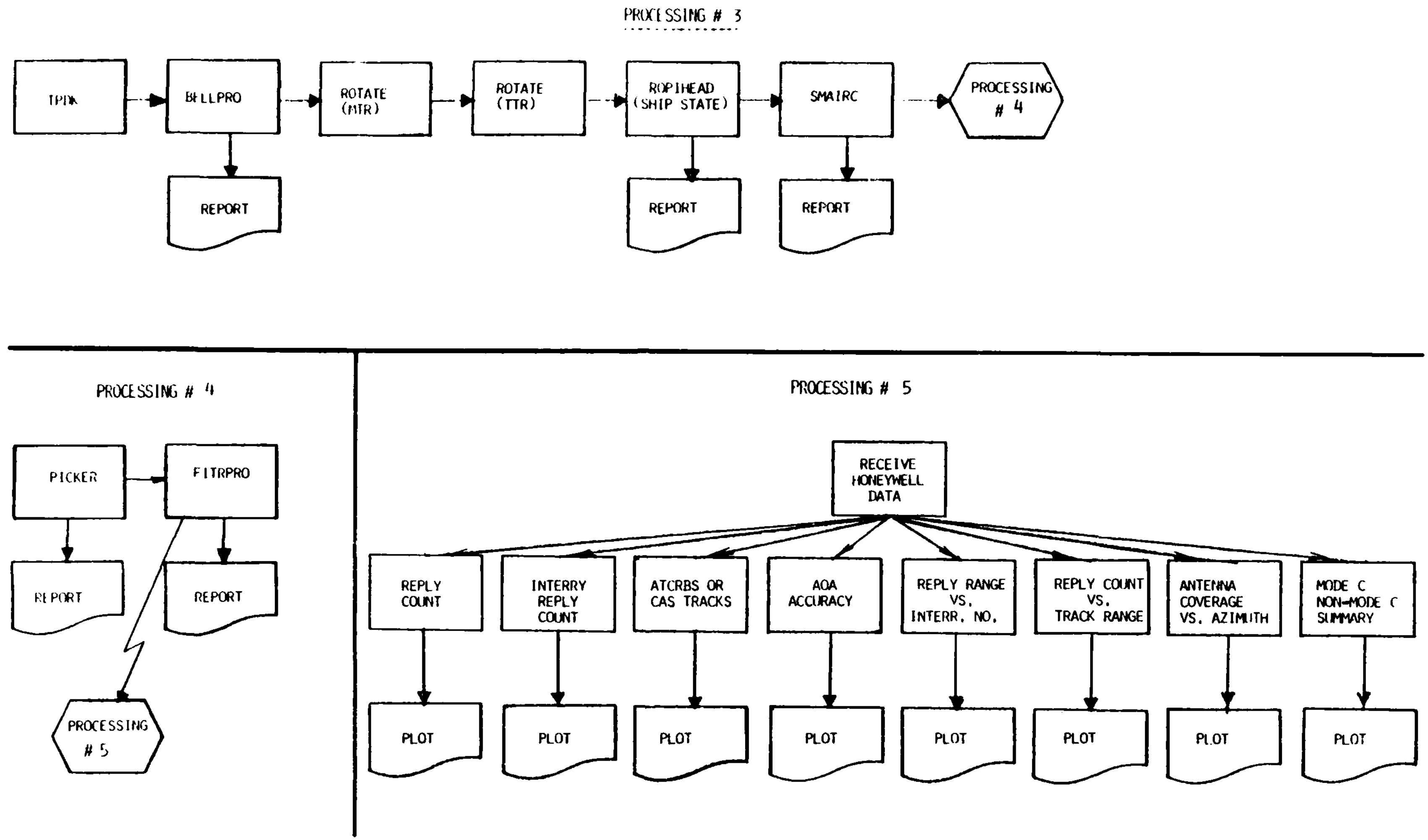


FIGURE 5. FLIGHT DATA REDUCTION FLOW CHART (SHEET 2 OF 2)

SORT/MERGE

Figure 5 depicts the Sort/Merge Processing #3.

The purpose of this procedure is to merge three types of data (TCAS recordings, radar tracker recordings, and ship state data) into one time-correlated disk file that describes the test flight.

The tracker tapes are processed by rotating the recorded data to magnetic north and writing the output to disk. The Ship State tape is processed through a Least Squares Fit program to establish a 1-second data sample and is written to disk. These three output files are merged relative to system time into one file that becomes input to Processing #4.

DATA EXTRACT.

Processing #4 (figure 5) enables any user to select from the master merged data file any information needed for additional data reduction. PICKER program interprets user options from the JCL string and generates an output file. This output file is then used as input to FITRPRO to generate listing, plots, and/or other disk files the user desires.

TEKTRONIX 4054 PLOTS.

The processing of plot data is shown in figure 5 (Processing #5).

Plot data files are transmitted to the Tektronix 4054 from the Honeywell time sharing system and written onto a 4054 magnetic tape cartridge. This becomes the source data for subsequent programs on the 4054. Processing #5 shows the flow and the various plots that are generated.

RESULTS - FACTORY TESTS

ACCEPTANCE TESTING AT DALMO VICTOR.

Four acceptance tests were conducted at the factory in the period May 1983 to June 1984. A digest of each test is contained in the paragraphs that follow (see also appendix E, items 18-23). A running problem list was maintained to document and track TCAS deficiencies observed in the acceptance tests. By May 1, 1983, virtually all items on the list were closed.

ACCEPTANCE TEST AUGUST 29 - SEPTEMBER 1, 1983, and September 18-21, 1983. A factory acceptance test on SN02 TCAS was conducted from August 29 to September 1 and repeated September 18-21. The first test was conducted per Dalmo Victor's test plan, document R-3711-10778, dated September 1983. Table 6 contains a list of tests completed.

Failures in the TCAS prototype forced the unit to remain at the factory for problem resolution. The test was repeated September 18-21. Additional tests were added (see table 6, "Special Tests") to show problem resolution. The equipment was accepted after the repeat test because all except five of the problems were closed. The remaining open items involved receiver sensitivity, air data computer interface, angle accuracy, nonlinear altitude tracker, and

TABLE 6. FACTORY ACCEPTANCE TEST SCHEDULE

Acceptance Test Paragraph No. (Ref. R3711-107781)	August 29 - September 1 and 18-12	October 30-31	February 6-16	April 13-16
2.1 Receiver test	*	*[2]	*	*
2.2 Reply processor test	* (Except 2.2.2)[1]	*	Not accomplished[3]	* (Except 2.2.2)[1]
2.3 Surveillance/CAS tracking	* (Except 2.3.2)[1]		* (Except 2.3.2)[1]	* (Except 2.3.2)[1]
2.4 Not used				
2.5 Transmitter test	*		*	*
2.6 Not used				
2.7 Display & mode controls test	*	*	*	*
2.8 Recorder test	*	*	* (Genesco - all modes)	*
2.9 Software controlled MTL test	*		*	*
2.10 Buffer overload test	*		*	*
2.11 Self-test	*		*	*
3.0 Not used				
4.0 Angle-of-arrival test	*	*	*	*
5.0 Rooftop antenna tracking test	* All recorder configurations	*	* (All recorder configurations)	*
6.0 Not used				
7.0 Aircraft interfaces	*		*	*
8.0 TCAS control test	*		*	
9.0 CAS logic validation	*	*	* (All except 19 thru 33)	*
Special Tests				
1. Substitute FAA target generator in scenarios	*			
2. Static target-range rate test	*	*		
3. Range gate lower limit test	*			
4. Receiver noise figure		*		
5. Degarbler test using three targets			*	

Note:

1. Mode S testing not accomplished
2. Special test No. 4 added
3. Static degarbler test deleted

*Indicates tests were completed

variable minimum triggering level. These problems were not considered to be the type that would affect engineering and subsequent operational testing.

The main result of the repeat test was the exact definition of the level of density conditions to expect data loss. Those results prompted Dalmo Victor, at the Technical Center's request, to delete all Mode S data messages which increased the data recording capacities.

ACCEPTANCE TEST OCTOBER 31, 1983. This was a limited acceptance test attempting to gather data produced by Dalmo Victor, in their eclipse simulation, showing resolutions to problems in SN02 TCAS documented in engineering evaluation. One problem, outstanding since September 21, 1983, acceptance test, was corrected and demonstrated in this test. That was the air data interface problem.

No outstanding problems remained as of this test.

ACCEPTANCE TEST FEBRUARY 6-16, 1984. Both TCAS prototypes were to be tested during this period. SN01 TCAS was conditionally accepted and shipped to the Technical Center for antenna tests; SN02 was retained at the factory for problem resolution. The outstanding problems in SN02 were out of specification receiver test and angle accuracy performance test, and degraded transmitter and whisper shout attenuator operation.

When the outstanding problems were resolved approximately 1 week later, Dalmo Victor personnel repeated the ATP unwitnessed by the FAA. The results were mailed to the FAA. FAA analysts and engineers examined the repeat test data and found them acceptable. At that point SN02 shipment to the Technical Center was authorized. The main emphasis of the SN02 factory test was the Genesco recorder test. A special test was requested of Dalmo to throughly test the Piedmont recording in all its modes. The test passed.

ACCEPTANCE TEST APRIL 3-4, 1984. The intent of this test was do a complete acceptance test on SN01 TCAS, and then to do interchangeability testing with components of SN02 TCAS. The emphasis was equally divided between gathering sufficient data to accept SN01 and to show interchangeability.

Several logic problems showed up which prevented FAA acceptance. These were: a traffic advisory was generated against a nonthreating aircraft, angle accuracy was out of specification, and intermittant weather radar display caused by a problem in the Sperry symbol generator.

These problems were resolved after the FAA team left. The tests were rerun by Dalmo Victor, and the data were shipped to the Technical Center for analysis. All problems were closed.

RESULTS - TECHNICAL CENTER TESTS

ENGINEERING EVALUATION.

BENCH TESTS SN01. Tests were performed on SN01 TCAS prototype when it arrived at the Technical Center for the first time. These data, recorded May 16, 1983, were to be used as baseline data for subsequent comparison.

1. Maximum Transmitter Power Output; data recorded May 16, 1983 (see table 7).

TABLE 7. MAXIMUM TRANSMITTER POWER OUTPUT MEASURED MAY 16, 1983

TPT	S1	P1	P2	P3	P4
1		3.6	3.6	3.6	3.6
24	24.8	27.7	27.2	27.7	27.7
44	21.2	23.9	23.9	23.9	23.9
64	21.2	23.9	23.9	23.9	23.9
79	16.6	19.3	19.3	19.3	19.3
80		9.0		9.0	9.0
81	7.7	10.0		10.0	10.0
82	9.0	12.5		12.5	12.4
83	11.9	14.5		14.5	14.4

Notes: All measurements are decibels above 1 watt (dBW).

Data from this test shows a maximum interrogation power output of 27.7 decibels (dB) (588 watts). The antenna feedline loss in the aircraft was 2.8 dB, ±0.1 dB for all cables. Antenna gain was measured at (-1 decibels referenced to an isotropic radiator (dBir) minimum). Therefore, the Minimum Operational Performance Standards (MOPS) requirement of total radiated power (TRP) = 51 decibels relative to 1 milliwatt (dBm) was met.

The diminished power output of the suppressions and successive interrogations is correct and is within the required 1/2 dB of the MOPS specified values.

2. Maximum Transmitter Power Output (repeated) (see table 8). Data Recorded July 26, 1983, all whisper shout levels were inspected this day. However, only data for the same measurements as were made May 16, 1983 are presented.

TABLE 8. MAXIMUM TRANSMITTER POWER OUTPUT DATA RECORDED JULY 26, 1983

TPT I	S1 0	P1 3.6	P2 3.6	P3 3.6	P4 3.6
24	24.3	27.2	27.5	27.2	27.2
44	20.7	23.5	23.7	23.5	23.5
64	20.5	23.7	24	23.7	23.7
79	16.0	19.0	19.1	19.1	19.1
80		8.5		8.7	8.7
81	8.35	10.4		10.5	10.5
82	10.6	12.0		12.0	12.0
83	12.1	14.6		14.7	14.7

Note: All measurements are dBW.

The agreement between the data sets is within 0.5 dB. The data sets were recorded using different techniques. The accumulated measurement error in the two techniques was kept to less than 0.5 dB.

3. Transmitter Frequency. Data recorded May 16, 1983. The transmitter frequency was measured to be 1030.3 megahertz (MHz).

4. Receiver Sensitivity. Data recorded May 16, 1983 (see table 9).

TABLE 9. RECEIVER SENSITIVITY MEASURED MAY 16, 1983

TPT	Receiver Port	RF Level (dBm)	Video Output	% Replies
1	0°	-63	1.8V	80
24	0°	-76	0.8V	80
25	90°	-63	1.7V	80
44	90°	-77	0.8V	90
45	270°	-63	1.7V	90
64	270°	-77	0.7V	80
65	180°	-62	2.1V	80
79	180°	-76	0.9V	80

These data show that the receivers are well balanced at the low power levels. Of the four receivers, the 270 degree had the lowest gain, and the 180 degree receiver the highest. Due to Variable Minimum Triggering level (VMTL), the 180 degree port should exhibit minimum sensitivity at -74 dBm; the measured value of minimum sensitivity is -76 dBm. Thus, the receive performance is adequate to satisfy the MOPS requirement for link round reliability.

5. Receiver Sensitivity. Data recorded June 23, 1983 (see table 10).

The set of data measured in June shows degradation in the 0° receiver, compared to the May 16 measurement, at the low power level. The receiver sensitivity had not degraded sufficiently to affect the transmit receive link reliability (link margin = 6 dB per MOPS design).

6. Receiver VMTL Threshold. Data recorded July 26, 1983 (see table 11).

Part of this test included measurements of receiver sensitivity yielding data identical to table 10. No significent change was observed so the data are not listed. The term "significant" here refers to errors that are beyond the measurement accuracy of the test equipment.

VMTL thresholds for corresponding whisper shout steps in the other direction were measured and found to be identical to the values shown in table 6, and so are not listed.

TABLE 10. RECEIVER SENSITIVITY MEASURED June 23, 1983

TPT	Receiver Port	RF Level (dBm)	Video Output (V)	% Replies
1	0°	-63	1.55	90
24	0°	-72	0.75	80
25	90°	-63	1.85	80
44	90°	-77	0.7	80
45	270°	-64	1.8	80
64	270°	-77	0.7	80
65	180°	-63	1.98	90
79	180°	-76	0.75	80

TABLE 11. RECEIVER VMTL THRESHOLD

TPT	VMTL Threshold (V)	RF Level (dBm)
1	1.6	-62
2	1.5	-63
3	1.4	-64
4	1.35	-65
5	1.25	-66
6	1.2	-66.3
7	1.1	-67
8	1.0	-67.8
9	0.9	-68.6
10	0.82	-69.4
11	0.78	-70.1
12	0.7	-71.5
13	0.6	-72.5
14	0.55	-73.4
15	0.45	-73.7
16	0.3	-74.6
17	0.3	-75
18	0.3	-75
19	0.3	-75
20	0.3	-75
21	0.3	-75
22	0.3	-75
23	0.3	-75
24	0.3	-75

7. AOA Processing - Receiver matching. Data recorded July 11 and 12, 1983.

Table 12 lists several combinations of TPT number and RF input levels, wherein the comment "did not track" is annotated. TCAS rejects replies whose AOA is more than 60° away from beam center in the direction of interrogation. This AOA filter is used to reduce fruit loading on the surveillance processor. Thus, those combinations of TPT and RF levels produced relies which were rejected as fruit.

BENCH TESTS SN02. A limited set of bench tests were performed on SN02 TCAS when it arrived from the factory in October 1983. The actual testing was a subset of tests conducted in the engineering evaluation of SN01 prototype.

1. Maximum Transmitter Power Output. Data recorded October 9, 1983. In this test, only the maximum power output in the forward direction was recorded. The maximum power in the other directions as recorded for SN01, was not recorded here because the emphasis of this test was to measure absolute maximum power.

TPT	S1	P1	P2	P3	P4
24	23.8	26.6	26.6	26.6	26.6

(Note: All measurements are dBW)

2. Maximum Transmitter Power Output (repeated). Data Recorded November 14, 1983. After a transmitter failure was repaired at the factory, the power was measured upon the transmitter's return to the Technical Center:

TPT	S1	P1	P2	P3	P4
24	24.5	27.2	27.2	27.2	27.2

(Note: All measurements are dBW)

This second set of data indicates a slightly higher transmitter output: 524.8 watts measured November 14, 1983, compared to 457 watts measured on October 10, 1983. Both measurement sets meet the MOPS requirement of +51 dBm TRP.

3. Transmitter Frequency. Data recorded October 9, 1983. The transmitter center frequency was 1030.2 MHz.

4. Antenna VSWR. Data recorded October 9, 1983. Antenna SN05 was installed on the aircraft. The feedline loss was 2.9 dB. The data were recorded at each beam direction (see table 13).

To each of the Prev readings, the two-way feedline loss must be added. After the Prev is normalized, VSWR can be computed according to the relation:

$$\mathrm{VSWR} = \frac{1 + 10^{-R/20}}{1 - 10^{-R/20}}$$

where R = Pfwd -Prev in dB, and equates to a ratio of powers.

Antenna VSWR is then computed (see table 14).

TABLE 12. MEASURED AOA VERSUS TPT NUMBER AND RF INPUT LEVEL

Date (1983)	Receiver	Input	Interr. #	Input Signal Level		Measured Angle in Deg.	Primary Power Supply
7/11	0°	270°	TPT 1	-50	-50	302	Conditioned (B ϕ)
7/11	0°	270°	TPT 1	-50	-51	302	Aircraft (Bϕ)
7/11	0°	270°	TPT 1	-50	-50	Did not track	Aircraft (Bϕ)
7/11	0°	270°	TPT 45	-50	-50	297	Aircraft (Bϕ)
7/11	0°	270°	TPT 45	-50	-53	312	Aircraft (Bϕ)
7/11	0°	270°	TPT 1	-50	-50	Did not track	Aircraft (Bϕ)
7/11	0°	270°	TPT 45	-50	-50	298	Aircraft (Bϕ)
7/11	0°	270°	TPT 1	-50	-51	305	Aircraft (Bϕ)
7/11	0°	270°	TPT 45	-50	-51	303	Aircraft (Bϕ)
7/11	0°	270°	TPT 2	-50	-50	Did not track	Aircraft (Bϕ)
7/11	0°	270°	TPT 2	-50	-50	301	Aircraft (Cϕ)
7/11	0°	270°	TPT 1	-50	-50	302	Aircraft (Cϕ)
7/11	0°	270°	TPT 1	-50	-50	301	Conditioned (Cϕ)
7/11	0°	270°	TPT 1	-50	-50	300	Conditioned (Aϕ)
7/11	90°	180°	TPT 65	-50	-50	138-156	Aircraft (Bϕ)
7/11	90°	180°	TPT 25	-50	-50	148	Aircraft (Bϕ)
7/11	90°	180°	TPT 25	-50	-50	148	Conditioned (Bϕ)
7/11	90°	180°	TPT 65	-50	-50	142-153	Conditioned (Bϕ)
7/11	90°	180°	TPT 65	-50	-51	139	Conditioned (Bϕ)
7/12	0°	90°	TPT 1	-50	-50(Start Up)	30	Conditioned (Bϕ)
7/12	0°	90°	TPT 1	-50	-50 (10 min)	45	Conditioned (Bϕ)
7/12	0°	90°	TPT 1	-50	-50	48	Conditioned (Bϕ)
7/12	0°	90°	TPT 25	-50	-50	45	Conditioned (Bϕ)
7/12	0°	90°	TPT 1	-50	-53	60	Conditioned (Bϕ)
7/12	0°	90°	TPT 25	-50	-53	62	Conditioned (Bϕ)

TABLE 13. ANTENNA VSWR MEASUREMENT

TPT	Beam Direction	Forward Power (Pfwd) in dBm	Reverse Power (Prev) in dBm
23	0°	P1 = 26, P2 = 25.8	P1 = 10.9, P2 = 11.7
42	90°	P1 = 22.2, P2 = 22.0	P1 = 7.1, P2 - 8.7
61	270°	P1 = 22.1, P2 = 21.9	P1 = 7, P2 = 8.7
75	180°	P1 = 17.3, P2 = 17.1	P1 = 3.2, P2 = 5.5

TABLE 14. CALCULATED ANTENNA VSWR

TPT	VSWR (P1)	VSWR (P2)
23	2.04:1	2.25:1
42	2.04:1	2.46:1
61	2.04:1	2.49:1
75	2.25:1	3.1:1

During the months of September and October, failures in the TCAS transmitter and W/S attenuator were frequent. ACT-140 engineers felt that excessive antenna VSWR might be contributing to premature failure of components. As the VSWR measurement was being made, it was observed that antenna switching was occurring while the transmitter output was a maximum. For a short time, full power was reflected back to the transmitter attenuated by the two-way feedline loss. However, subsequent information from the manufacturer indicated that the failures were not correlated and were not caused by the excessive VSWR.

5. Receiver Sensitivity. Data Recorded October 13, 1983 (see table 15).

TABLE 15. RECEIVER SENSITIVITY DATA

TPT	Receiver Port (degrees)	RF Level (dBm)	Video Output	% Replies
1	0	-60	1.51	90
24	0	-77	0.3	80
25	90	-62	1.50	80
44	90	-77	0.3	80
45	270	-61	1.52	80
64	270	-76	0.31	80
65	180	-61	1.52	80
79	180	-76	0.31	80

6. Receiver VMTL. This test not performed on SN02 TCAS at the Technical Center.

7. AOA Processing - Receiver Matching. Data recorded January 8, 1984. Table 16 shows the data from this test; including video voltage output (V), mean angle difference from the cardinal axis (M), and standard deviation of the data around the mean. These data were taken over the range of input levels from -76 dBm (corresponds to 13 dB attenuation) to -63 dBm (corresponds to 0 dB attenuation).

STATIC TEST BOTH UNITS. Static or ramp tests were conducted to evaluate the transmit and receive antenna patterns. Some limited AOA accuracy testing was also accomplished, but only in support of the pattern measurements and subsequent data analysis.

Transmit Patterns. Data recorded July 29, 1983. To pursue a problem in aircraft tracking at the 0° and 270° axes, a measurement was made on antenna SN02 to determine the actual radiation patterns of interrogations transmitted by the antenna. The P1 pulse in TPT 24 is considered to be 0 dB level; all other data are in dB referenced to this zero level (see table 17).

These data are interpreted by taking the difference between adjacent points in the table. For example, the S1 pulse is -3.5 - (-5) = 1.5 dB below the P1 pulse for TPT No. 20.

Receive Patterns. A total of three antennas were measured in the static tests. The data are contained in appendix A. The three antennas were SN02, SN05, and SN06.

1. SN02 results. Static tests on this antenna showed excessively high side lobes and back lobes in the video pattern (figure A-8, appendix A). The voltages at the I.F. output of each of the receivers were measured twice (figure A-8 and A-9 of appendix A), because the first measurement showed an apparant increase in gain of the receivers. The second measurement, however, also showed a distortion in the intermittent frequency (IF) output. In a subsequent acceptance test, an intermittant was found in the 90° receiver which accounted for the shift in the IF voltage. The cause of the excessive back-lobes and side-lobes amplitudes was a VSWR mismatch in the antenna to receiver interface. That problem was corrected by impedance matching in the antenna phase shifting microstrip circuitry.

2. SN05 results. Static tests on this antenna showed an increase in the lobing in the RF pattern and also changes in the locations of the lobes (figures A-4 and A-5, appendix A). Normally, the locations of the side and back lobes would be away from the pattern crossover points, but the lobes in SN05 occur near the crossovers.

Computer simulation at the Technical Center failed to reproduce the second condition in SN05, where the lobes changed location, by variations in the phase and amplitudes to the driven elements. Only by changing the location of the elements (in simulation) was the condition duplicated.

TABLE 16. AOA PROCESSING - RECEIVER MATCHING

Attenuation (dB)	0°			270°			180°			90°		
	V	μ	σ	V	μ	σ	V	μ	σ	V	μ	σ
0				1.45	-1.5	.15	1.5	0	0			
1												
2	1.15	+1.15	1.9							1.2	-3.2	5.8
3				1.25	-3.5	5.2	1.3	0	0			
4												
5	0.9	+9.4	3.5							0.8	-10.4	21.6
6	0.8	12.1	3.1				1.0	-1.1	18.8	0.75	-11.5	28.8
7	0.73	13.6	6.7	0.90	-21.5	38.2	0.8	5.0	9.0	0.70	-0.32	7.7
8	0.6	17.0	7.8	0.80	-18.1	14.3	0.75	5.0	15.2	0.60	-17.2	26.8
9	0.6	19.3	3.2	0.75	-15.5	20.7	0.70	4.5	15.7	0.55	-13.9	27.3
10	0.5	16.9	2.6	0.65	-26.5	14.2	0.60	-3.4	20.2	0.50	-10.3	31.8
11	0.45	20.3	2.0*	0.60**	-23	23.8	0.55	3.5	19.4	-	-	-
12	-	-	-	0.60**	-29.2	17.5	0.50*	9.0	18.5			
13				0.45	-21.6	27.3	-	-	-			

Notes: *10 Points
**11 Points
No asterisk 15 points

TABLE 17. ANTENNA SN02 INTERROGATION PULSE FIELD DATA

TPT	S1	P1	P2	P3	P4	True (degrees) Bearing
20	-5	-3.5	-17.5	-2.5	-2.5	0°
22	-4.5	-1.5	-15.5	-0.5	-0.5	0°
24	-3	0	-14	0	0	0°
60	-23.5	-19.5	-33.5	-17.5	-17.5	270°
62	-18.5	-18	-31.5	-17.5	-17.5	270°
64	-17	-14.5	-30.5	-15	-15	270°

Note: True bearing is the bearing measured from the TCAS aircraft to the test van.

The video patterns demonstrated by SN02 and SN05 created a unique signature. In flight testing (orbits) the displayed bearing (rho-theta) tracked the target past the cardinal axis and then, as the target continued his orbit, the displayed bearing reversed direction and moved back to the axis. This behavior is directly related to the high side lobes. Angles were correct in the region away from the lobes. With the excessive lobes though, the angle processing circuitry began to consistantly pick the wrong quadrant, and CAS began to track the bearing angle in reverse.

3. SN06 results. The static patterns on SN06 were measured after the antenna was exposed to stress tests at the factory and again at the Center. The factory tests were performed in an environmental chamber which cycled temperature, pressure, and humidity. At the Center, the antenna was mounted on the aircraft. The aircraft was parked on the ramp for 2 hours, in direct sunlight, with 80° ambient temperatures. After takeoff, the aircraft climbed rapidly to 37000 feet. The patterns shown in figures A-11 and A-12, appendix A, show excellent agreement with anechoic chamber data from the factory gathered before the stress testing. Technical Center engineers working with Lincoln Laboratory engineers concluded that the antenna was stable.

FLIGHT TEST. The results of the various sections of the flight test program are described in the paragraphs that follow.

CAS Validation. The results of the Center's CAS logic analysis are contained in this section.

There were 253 planned resolution advisories generated in the evaluation period. Data from each encounter is contained in graphs which are found in appendix D. Appendix D is organized into groups which are separated according to major activity:

Pages D-1 to D-6:	Group 1	May-July 1983	Engineering evaluation, serial 01
Pages D-7 to D-12:	Group 2	October 1983	Engineering evaluation, serial 02
Pages D-13 to D-18:	Group 3	November 1983	Operational evaluation, serial 02
Pages D-19 to D-24:	Group 4	April 1984	Dry run certification testing, both systems
Pages D-25 to D-30:	Group 5	April-June 1984	Dry run certification testing, both systems

Each group contains six graphs which show the initial resolution advisory selection, secondary resolution advisory selection, and tau based threat detection criteria. Each graph has superimposed truth data derived from the version 11.0 logic (appendix E, item 8). Inspection of each graph quickly shows any out-of-tolerance parameter.

Each graph is interpreted as follows: For example, appendix page D-19 shows the selection of resolution advisories in the dry run missions for certification. The axes are labeled Current Altitude Separation in feet (defined as own minus intruder) and Projected Vertical Miss Distance in feet (positive values indicate own will pass above). Superimposed on the graph are lines which define various zones where certain RA's should occur, based on the CAS logic parameter "Layer." This particular graph contains data for altitude Layer 1. The symbols on the graph represent the actual advisories generated; for example, a "1" indicates a climb advisory.

Page D-20 shows the selection of resolution advisories for altitude Layer 2.

Page D-21 shows a graph of Projected Vertical Miss Distance (in feet) versus true Tau (in seconds). Occasionally, the initial resolution advisory is weakened due to vertical divergence. This graph shows the permissible states in which TCAS can weaken the advisory, based on altitude Layer 1.

Page D-22 shows the data for Layer 2.

Pages D-23 and D-24 show graphs, performance level dependent, of range versus range rate (which defines the parameter tau). The tolerance bands define the permissible regions for traffic and resolution advisory selection based on tau.

A compact summary of the results of the CAS logic evaluation appears in table 18. The table shows, by group, the numbers of expected and measured RA's by RA sense and type for initial RA selections (nonparenthetical numbers) and secondary RA selections (numbers in parentheses). Detailed descriptions of the results of each group are contained in the following paragraphs.

<u>Engineering Evaluation. Serial No. 01</u>. (Refer to pages D-1 through D-6.) No encounters were flown in Layer 1 during this period (see page D-1, Total Encounters = 0). Page D-2 shows 40 encounters. Of these, three yielded incorrect resolution advisories which would have decreased vertical separation. All three were caused by a coding error in the CAS logic module called "Detection." Specifically, the error was in a section of code which inhibits

TABLE 18. SUMMARY OF THE CAS LOGIC EVALUATION RESULTS

Number of RA's by Group

RA Type	Group 1 Expected***	Group 1 Measured	Group 2 Expected	Group 2 Measured	Group 3 Expected	Group 3 Measured	Group 4 Expected	Group 4 Measured	Group 5 Expected	Group 5 Measured
Climb Sense	19 (23)**	19 (25)	30 (7)	26 (22)	55 (31)	56 (31)	24 (6)	24 (6)	17 (2)	17 (2)
Climb	11 (8)	11 (8)	17 (11)	15 (11)	38 (14)	39 (14)	16 (4)	16 (4)	12 (2)	12 (2)
LVR* 0	7 (14)	7 (16)	8 (10)	6 (8)	14 (7)	14 (7)	7 (0)	7 (0)	5 (0)	5 (0)
LVR 500	0 (1)	0 (1)	4 (3)	4 (3)	2 (5)	2 (5)	1 (0)	1 (0)	0	0
LVR 1000	1 (0)	1 (0)	1 (0)	1 (0)	1 (14)	1 (14)	0 (1)	0 (1)	0	0
LVR 2000	0 (0)	0 (0)	0	0	0 (1)	0 (1)	0 (1)	0 (1)	0	0
Descend Sense	22 (21)	22 (19)	15 (10)	18 (13)	12 (4)	12 (4)	29 (2)	29 (2)	15 (5)	15 (5)
Descend	21 (10)	21 (10)	14 (7)	16 (8)	7 (2)	7 (2)	21 (0)	21 (0)	10 (0)	10 (0)
LVR 0	1 (10)	1 (8)	0 (2)	1 (4)	2 (2)	2 (2)	8 (0)	8 (0)	4 (1)	4 (1)
LVR 500	0 (0)	0 (0)	1 (1)	1 (1)	1 (0)	1 (0)	0 (2)	0 (2)	1 (1)	1 (1)
LVR 1000	0 (0)	0 (1)	0	0	0	0	0	0	0 (3)	0 (3)
LVR 2000	0 (0)	0 (0)	0	0	2 (0)	2 (0)	0	0	0	0
Maintain Altitude	0	0	0	0	0	0	0	0	0	0

Notes:

*LVR denotes "limit vertical rate." LVR 0 in the climb sense means do not descend; LVR 1000 in the descend sense means don't climb faster than 1000 feet per minute, etc.

**The nonparanthetical numbers denote the number of occurrences of initial RA selection. The numbers in parantheses denote secondary RA selections; that is a change in the first RA issued in the encounter.

***Values under "Expected" should always equal corresponding values under "Measured." If they do not (for example, see primary RA selections for "climb sense" - Group 2) the presence of a logic or coding error is indicated. The text description for each group provided detail.

firmness delays when reasonable confidence bounds can be established for the intruder's vertical rate. In this code, the climb and descend resolution advisories are modeled against the rate bounds for the intruder. The RA is chosen which provides better separation. In Dalmo Victor's implementation the associated variables were being treated as unsigned integers. Negative numbers which naturally resulted were being treated as large positive values and were, invariably, causing the wrong advisories.

In the three advisories (noted 1, 2, and 3) the confidence bounds, ZDINNER and ZDOUTER, were equal in value, which should result in either a clear selection of the proper RA or a firmness delay.

This logic error was reported to Dalmo Victor as Trouble Report number 34, item G. Dalmo incorporated the logic correction January 19, 1984. While this error was reported to Dalmo by the Technical Center, Dalmo analysts had already been examining it after having completed testing of approximately 1500 scenarios (in simulation), and a verification of the code implementation.

Page D-4 shows the secondary RA selections for the same period. A total of 44 RA changes were generated by TCAS after the initial advisory selection. Of these, three were incorrect. The error was in a section of code dealing with slow closing rate encounters. This particular error occurs consistently during altimeter calibration runs. These are runs where the Convair aircraft maneuver at the Boeing 727 in order to effect formation flying. When in wingtip to wingtip formation, the pilots of each aircraft verify their altimeter indications.

For a description of the nature of the coding error and the dates reported, see the discussion on Group 2 - Engineering Evaluation Serial No. 02.

Pages D-5 and D-6 show the traffic and resolution advisory threat criteria - range and range rate. All TA symbols (circles) should appear within the TA limits and all RA symbols (asterisks) should appear in the RA limits. Exceptions are TA's from non-Mode C intruders. They appear as TA symbols (circles) in the RA limits.

Several TA and RA symbols appear in the region above and to the left of the limits, these are late. Late advisories were always caused by late track acquisition in surveillance (see the discussion of surveillance tracking in the next section, "Engineering Evaluation Serial No. 2").

Engineering Evaluation. Serial No. 02. Page D-8 shows 41 resolution advisories for Layer 2. Of these three were in error. The errors were caused by coding errors of the CAS logic. Note 4 (track ID=31) was an error in the modeling process reported by T. Choyce, ACT-140, in an informal memo on October 18, 1983. Note 5 was another manifestation of the unsigned integer problem which appeared in Group 1 - Engineering Evaluation, Serial No. 01. Note 6 was a result of incorrect initialization of the CAS vertical tracker using surveillance track data.

Note 2 points out a resolution advisory which is apparently incorrect. The problem was actually a data recording problem which failed to record the CAS data at the time the RA was actually issued. This particular encounter was intended to be a level off and fake out. The fake out was accomplished and

TCAS correctly chose the RA, but only the track data after the intruder leveled off was recorded.

The logic errors discovered in this group were reported to Dalmo Victor on October 19, 1983, and were implemented October 30, 1983.

Figure D-10 shows the secondary RA transitions. Thirty-five RA transitions were recorded. Of these, three were incorrect (see D-10, note 3). All three reselections occurred during the same RA sequence, which is not coincidence considering the nature of the coding error. The coding error occurred in a section of CAS designed to protect against slowly convergent (or divergent) intruders within the range defined by a CAS parameter called DMOD (see appendix E, item 8). Two variables, ZMPCLM and ZMPDES, were not being stored properly. Therefore, when CAS accessed the locations of these variables, nonsense values were returned, with the result that incorrect secondary RA's would always be issued against the intruder. In other words, CAS correctly executed the algorithm using wrong intruder data, and that is why the same RA sequence showed three incorrect RA's.

This error was reported to Dalmo Victor in the engineering review held at the Technical Center in October 1983. The error appears as Trouble Report No. 8. The logic correction was installed by October 30, 1983. Figures D-11 and D-12 show the values of true tau at the time of primary RA selection. Circles which appear in the traffic advisory boundaries are TA's against Mode C equipped intruders. Circles in the resolution advisory boundaries are TA's against non-Mode C equipped intruders. Asterisks in the RA boundaries are RA's against Mode C intruders (no RA's are generated for non-Mode C threats). Circles and asterisks which lie above and to the left of the boundaries denote late advisories which resulted from late surveillance track acquisitions.

Operational Evaluation. Serial No. 02. Figure D-14 shows 70 RA selections, one of which is in error. This error is a manifestation of the unsigned integer coding error described in the discussion of the Engineering Evaluation, Serial No. 01. This problem was reported as Trouble Report No. 34, item G; the correction was incorporated by Dalmo Victor in January 1984.

The erroneous RA was a "climb," issued against a Convair 580 who was maneuvering for altimeter calibration. The advisory did not transition to a TCAS abort because the intruder never got close enough to invalidate the climb maneuver. This error went unnoticed until the operational evaluation data were gathered for this report.

Figure D-16 shows 35 secondary RA selections. Of these, none were incorrect. One RA selection (note 1) appears out of place, but, in fact, is logically correct. The initial RA was "don't descend" against an intruder level, 700 feet below. The intruder then climbed sharply which forced TCAS to issue a climb advisory in order to maintain safe separation. At the time the climb was issued, the intruder was projected 206 feet above at CPA.

Figures D-17 and D-18 show that 24 percent of the TA's and RA's were late. Surveillance tracking of the Convair aircraft was not adequate during this period. The problem was partially due to TCAS, caused by antenna pattern deformation, and partially due to the transponders installed on the Convairs.

After extensive testing on the transponders, it was concluded that they are hypersensitive to suppression pulses in the W/S interrogation sequence.

The antenna pattern deformation compounded the problem by distorting the relative amplitude of the interrogation-suppression pulses seen by the victim transponder. In the discussion of Groups 4 and 5, the antenna pattern problem was corrected and tracking of the Convairs improved.

Certification Testing, Both Systems (Group 4). Pages D-19 and D-20 show 54 encounters, all of which are correct.

This discussion refers to prototype systems A and B. System A consists of serial No. 2 computer unit (6 mcu) and serial No. 1 RF unit (8 mcu). System B consists of serial No. 1 and serial No. 2 RF. This pairing of units was done because No. 2 computer and No. 1 RF were more reliable and, therefore, was made the primary system. System B was considered the backup system.

Pages D-20 and D-21 show eight secondary RA's, all correct. A particular point of interest on pages D-20 and D-21 is that the secondary RA selections fit nicely in the boundaries shown. This shows that surveillance was fuctioning well because the boundaries define RA regions given good track firmness. In the associated figures for previous evaluation groups, many secondary RA's were scattered about the climb or descent sense regions. This is an indication that these RA's were picked on low firmness.

Pages D-22 and D-23 show the tau selection criteria. Page D-22 is nearly flawless. Thus, Convair tracking is adequate for performance level 5. The remaining encounters were flown against a Cessna Citation and a Lockheed Jetstar. Page D-23 shows that Convair tracking (about 80 percent of the total RA's) is still marginal in performance level 6. Seventeen percent of the advisories were late. Three of the late advisories were non-Mode C TA's against the Convair operating with Mode C off. Of the four late RA's, none provided less than 20 seconds warning time. Overall, the performance with the new antenna was greatly improved compared to the defective antenna.

Certification Testing, Both Systems (Group 5). Pages D-19 to D-22 show 33 primary and 7 secondary RA selections. There are no errors. The same comments made in the discussion of Group 4 apply here as well.

Pages D-23 and D-24 show the tau selection criteria. Layer 1 performance is adequate, layer 2 performance is marginal. It should be emphasized here that late advisories are due to surveillance performance and not due to a CAS logic error.

Summation of CAS Logic Errors. Table 19 is a listing of the errors discovered in CAS during the evaluation period.

Summation of the CAS Evaluation. The CAS logic functions predictably when the firmness of the intruder track is high. This is illustrated by the graphs in appendix D which show the initial resolution advisory selection (e.g., D-1, D-2, D-7, D-[illegible], etc.). The symbols that show the RA's are within the defined areas.

TABLE 19. CAS LOGIC ERRORS ACCUMULATED DURING THE EVALUATION PERIOD

Date of Error	Error Type	Trouble Report No.	Date Corrected
5/25/83	Signed/unsigned comparison	34, item G	1/19/84
5/25/83	Signed/unsigned comparison	34, item G	1/19/84
5/25/83	Secondary RA	4	10/30/83
6/24/83	Secondary RA		
6/24/83	Secondary RA		10/30/84
6/24/83	Secondary RA		10/30/84
6/28/83	Signed/unsigned comparison	34, item G	1/19/84
7/21/83	Buffer overwrite		
10/7/83	Vertical tracker init.	9	10/30/83
10/17/83	Secondary RA selection		
10/17/83	Signed/unsigned comparison	34, item G	1/19/84
10/18/83	Memo by T. Choyce		10/30/83
10/18/83	Secondary RA selection		10/30/84
10/18/83	Secondary RA selection		10/30/84
11/08/84	Signed/unsigned comparison	34, item G	1/19/84
11/08/84	Variable sign error	34, item G*	1/19/84
8/21/84	Vertical tracking error		

*This error is distinct from the signed/unsigned comparison error but is included in Trouble Report No. 34.

When firmness is low, however, advisory selection is less predictable (illustrated by the same graphs). For example, see note 1 on figure D-27. RA selection on low firmness is done in one of two modules; "DETECT" or "RESCOOR." If DETECT is invoked, the advisory is picked on rate bounds established around the intruder's vertical trajectory. If RESCOOR is invoked, the advisory is picked on the actual intruder trajectory, which is more in line with the CAS philosophy.

The intent of the logic which selects an RA despite low firmness is to allow RA selection which otherwise might be delayed an inordinate amount of time, thus, leaving insufficient to maneuver. While the intent is good, the implementation has a particular sensitivity to intruders whose surveillance tracks are coasting approximately 40 percent or more. Cases of planned encounters have been observed where an intruder was closing, level, and vertically separated by 200 to 250 feet. Just before the RA was selected, the intruder drifted across an altitude bin causing TCAS to establish rate bounds which favored an altitude crossing advisory. Because the planned scenario called for level flight by both aircraft, the RA was not followed, and a TCAS invalid advisory was generated.

The event described in the previous paragraph is rare. The point is made here to motivate a close scrutiny of Piedmont flight data to catch degradation in surveillance performance manifested by excessive surveillance track coasting.

In another case, CAS may issue a positive advisory (e.g., climb) against an intruder who is VFR separated (i.e., 500 feet low) if the track firmness is low, again due to coasting in the track of a nonmaneuvering intruder. This event has drawn criticism from subject pilots who witnessed it because they felt that an escape maneuver was unnecessary with 500-foot separation, and that too many maneuvers would be required when flying in mixed VFR/IFR traffic areas.
The remainder of the logic is unaffected by track firmness.

<u>Aircraft Interfaces</u>. Results of the testing (and retesting after problem resolution) are listed below.

1. Radar Altimeter and Status. In the current configuration, TCAS will go in performance level 1 and issue a self-test failure if the radar altimeter status flag goes invalid. On several occasions during Technical Center flights, and once on the national tour, a radar altimeter failure took TCAS to performance level 1, an inactive state. Also, resolution advisories were interrupted when TCAS overflew the target aircraft which echoed the radar altimeter's interrogations. The sudden altitude change caused the altimeter to fail self-test momentarily.

The radar altitude sensing functioned as follows (see table 20):

TABLE 20. RADAR ALTIMETER BAROMETRIC ALTIMETER COMPARISON

Barometric Altitude*	Radar Altimeter Output	TCAS Measured Altitude
0	0 dc	0
100	2 dc	106.3
200	4 dc	193.8
300	6 dc	300.0
400	9 dc	381.3
500	11 dc	468.8
1000	17 dc	981.3

*Note: Measured barometric pressure was normalized to 29.92 inches of mercury.

2. Gear and Flaps Interfaces Were Correctly Sensed. In the data printouts, gear and flaps deployed are indicated by a "zero."

3. Pressure Altitude. Data from the flights was scanned for missing or incorrect codes. No evidence of this was noticed.

TCAS has a self-test function to detect a failure in the pressure altitude face. If an illegal altitude code from own ships altimeter was recognized by TCAS, a self-test failure was generated and the failure code "F-6" was declared. This failure occurred early in the engineering evaluation May 27, 1983, when an altitude interface problem surfaced. The problem was corrected.

4. Air/Ground Switch. When the aircraft left the ground the sense of the craft changed. In the data printouts, the sense of the "squat" switch changed line 1 to 0 each time, and the CAS performance level changed from 1 to 2 when the air from left the ground.

5. Weather Radar Status Input. This input was verified during the factory acceptence test.

6. Mutual Suppression. This is a critical interface. During one of the engineering flights, a faulty BNC connector caused the interface line to be disconnected from the aircraft bus. Immediately, TCAS began to interrogate own ship's transponder resulting in a descend resolution advisory and subsequent TCAS Invalid against a target at zero range, coalitude. To the pilots, the event looked like a pop-up leading to an imminent collision. No other problems with this interface occurred. Future TCAS should incorporate a bus sensor to detect

other system's suppression pulses indicating an active bus. In the event of bus failure, TCAS should cease interrogating.

7. Genisco Recorder (ECR-10). In flight testing at the Technical Center, the ECR-10 operated in all modes. Proper operation in all modes was also demonstrated in a factory acceptance test held February 13 - 15, 1983.

8. Performance Level change versus altitude. A subset of the radar and pressure altitude interface tests is the change in the CAS sensitivity level as a function of altitude. The designator of CAS sensitivity is called performance level. The design thresholds, and actual thresholds of performance level change are shown below (table 21):

TABLE 21. MEASURED VERSUS DESIGN VALUES OF PERFORMANCE LEVEL CHANGE

Performance Level	Design Altitude Threshold	Measured Altitude Threshold
1	0 (on ground)	Set by weight on wheels
2	0-500 feet AGL	0-500 feet AGL*
4	500-2500 feet AGL	500 feet AGL*
5	2500-10,000 feet m.s.l.	2500-10,000 feet m.s.l.
6	Above 10,000 feet m.s.l.	Above 10,000 feet m.s.l.

Note:

AGL is a radar altitude dependent parameter.

m.s.l. = mean sea level and is a barometric altitude dependent parameter.

*Threshold is 500 feet if no gear and flaps are deployed. If both are deployed, the threshold is 700 feet.

Accuracy Analysis. Several flights were made for accuracy testing. One flight was devoted to range and altitude tracking accuracy; four flights were devoted to AOA accuracy. The flight dates and associated results are listed by flight day.

Flight of June 16, 1983. After the encounters were completed, two orbits were completed to test the range and altitude and bearing tracker accuracies, and validate the data reduction procedure of the precision trackers. The results of the flight were:

1. Range Accuracy. The statistics of the accumulated data are: mean error = -160.6 feet, standard deviation = 173.3 feet (assuming a rectangular distribution).

2. Range Rate Accuracy. The range rate data was unimodal with the statistics mean error = -0.42 kts and standard deviation =10.4 kts (assuming a rectangular distribution). In factory acceptance testing, stationary targets showed instantaneous range rates of up to 36 kts due to the range clock ambiguity.

3. Altitude Accuracy. This is unimodal data with mean error = 40 feet and standard deviation = 20 feet. These errors include the $\pm$50-foot quantization inherent in the barometric altimeters.

4. Altitude Rate Accuracy. This is also unimodal data with mean error = -0.37 feet per second and standard deviation = 14.4 feet per second (assuming rectangular distribution).

The accuracy statistics provided above are the results of comparison of CAS tracker data with precision radar tracking data. The point is made here to avoid confusion regarding exactly which TCAS subsystem, i.e., front end, surveillance, or CAS, was being evaluated.

5. Bearing Tracker Accuracy. No data. The problem was an incorrect transfer of bearing data from the raw replies to the track file. As a result, the bearing track coasted almost constantly producing meaningless bearing data.

Flight of June 22, 1983. To facilitate the bearing accuracy analysis, the problem of June 15 was circumented by terminating the bottom (omni) antenna, forcing the bearing tracker to use valid replies. The results are shown in appendix A, figures A-1 and A-2.

Flight of November 21, 1983. This test was conducted using SN05 antenna and SN02 TCAS. The results are shown in appendix A, figures A-3 and A-4.

Flight of February 17, 1984. This was conducted using SN06 antenna and SN01 TCAS. The results are shown in appendix A, figures A-5 and A-6.

Multipath Rejection. The scenario for this test was TCAS at 2200 feet m.s.l. over water and the target aircraft flying parallel at 2 nautical miles (nmi) and 2200 feet m.s.l. off the right wing. In order to test the multipath rejection logic, the range of the target aircraft was slowly varied between 2.5 and 1.5 nmi. Several times during the test multipath targets were displayed on the CRT. The condition was most prevalent between 1.6 and 1.9 nmi. At times the multipath target was a nonbearing target; at other times it was a bearing target.

A post-flight review of data identified many multipath periods for the target aircraft. The information is shown in table 22.

TABLE 22. RESULTS OF THE MULTIPATH REJECTION LOGIC TEST

Total real tracks examined:	19
Total proximity advisories due to real tracks:	19
Total multipath tracks observed:	18
Total proximity advisories due to multipath tracks:*	10
Proximity advisories less than 5 seconds:	3
Proximity advisories more than 5 seconds:	7
Total events where multipath track was detected and deleted:	14
Total events where multipath went undetected and coasted out:	5

*Proximity advisories due to multipath caused display clutter when the multipath symbol overlapped the real aircraft symbol.

In reviewing the flight data several observations were made:

1. Fourteen out of 19 times the multipath condition was detected and the multipath track dropped without coasting.

2. On five occasions the multipath condition went undetected and the track coasted out.

3. On several occassions (marked by *) the correlation process correlated the large range (multipath) reply with the existing track rather than the multipath tracks.

4. Ten out of 19 multipath periods progressed to impact the display status.

5. When a track is discarded due to multipath rejection, the display hysteresis is not invoked. This is a proper result.

6. Other periods of multipath with targets of opportunity were also observed.

As a result of this work, Dalmo Victor incorporated a 1-second delay between the time a new track is acquired in surveillance and the time it is established in CAS (eligible for display). This action reduced the display of multipath tracks by approximately 20 percent.

TCAS Performance in Terminal Operations. Missions, consisting of approaches to local airports, were conducted during the entire TCAS evaluation program. Typically, four to six approaches terminating in missed approach and departure procedures were completed each mission. The TCAS data provided valuable information regarding the operational environment.

Appendix B contains summaries, on a daily basis, of all the approach missions from the engineering evaluation, operational evaluation, and the national tour. Each summary provides the following:

Title Page

1. Mission number.
2. Destination city.
3. Total flight time.
4. Purpose of flight.
5. Date.
6. Total number of advisories and number of advisories that would not have occurred if the Piedmont on-the-ground supression logic were installed.
7. Percentage of time the TCAS displayed bearing was invalid.
8. TCAS configuration.
9. Problems observed in flight.

Information Page

1. Number of events including TA's and RA's.
2. Description of each event and whether the advisory would have been suppressed if the Piedmont on-the-ground suppression logic was installed.
3. General flight results.

Data Page

1. Plots of aircraft density.
2. Transition matrix.

The title page contains information regarding the number and types of advisories to be expected on an approach to the airport listed. The title page also lists the percentage of the time the intruder bearing was invalid. This measure indicates the time that the intruder was shielded from the top (directional) antenna and was being tracked on the bottom omnidirectional antenna.

The information page shows each advisory generated by TCAS; an explanation of the columns follows:

1. Advisory Type - indicates TA-Mode C or non-Mode C; or RA and type.

2. Duration - indicates the time duration of the advisory.

3. Warning Time - indicates the time before CPA that the advisory was issued.

4. Track ID - this the intruder track identification number used in CAS.

5. Bad Bearing - indicates incidence of loss of bearing and duration of time in seconds that bearing was not presented.

6. Projected Miss (VMD) - projected vertical separation at closest point of approach.

7. Actual Miss Range, Altitude - actual miss distance given in range and relative altitude at closest point of approach.

8. Advisory Driven By - CAS logic parameter that triggered the threat logic.

9. Advisory Inhibit - indicates if the advisory would have been suppressed if the Piedmont logic were installed. Yes-1 indicates suppression by intruder on ground logic, yes-2 indicates suppression by multipath rejection, and yes-3 indicates suppression by false track advisory rejection.

10. Phase of Flight - indicates flight condition e.g., approach, en route, final, etc.

11. Performance Level - indicates CAS sensitivity level; defines protection volume.

12. TCAS altitude - indicates own ship barometric altitude.

13. Notes:

Density plots. The plots of aircraft density were generated by counting the aircraft tracks in surveillance. To prevent erroneous counts due to short lived false tracks (which occasionally form on fruit), a data filter is employed: only tracks which have been updated twice since formation are counted as real tracks. Typically, a real track will be updated twice within 2 or 3 seconds, while a false track will form and coast out immediately. Counts of aircraft tracks are accumulated once per second.

Transition matrix. Aircraft in track by Dalmo Victor TCAS surveillance are interrogated once per second. Occasionally, a reply from a victim aircraft will not be received for one or more successive scans. When surveillance receives no reply to update a track, the track is coasted. Tracks are allowed to coast for 5 consecutive seconds before being dropped.

The transition matrix shows each present coast state (rows) and each future coast state (columns). The entries are probabilities which identify the likelyhood of transitioning from any current coast state to any future coast state. For example, the entry at row 0 - column 0 specifies the probability that a track currently in coast state zero will remain there (i.e., a track updated last second will again be updated). As a second example, the entries at row 2 - column 3 and row 2 - column 0 indicate that a track currently in coast state 2 (not updated last 2 seconds) will either coast next second (row 2 - column 3) or be updated (row 2 - column 0).

Table 23 contains data extracted from appendix B. It is organized as "approaches," "en route," or "surveillance." Approaches refer to operations

TABLE 23. SUMMARY OF RESULTS OF APPROACH MISSIONS FLOWN BY TCAS

Mission Type	Airport	Total Flights	Total Flt Time	Total Advisories* TAMC	TANMC	RA	Density** Min.	Max.	Notes
Approaches	Atlanta (ATL)	2	4:21:47	9	6	1	0.003	0.055	RA's on target of opportunity (TOP
	Norfolk	1	2:09:34	6	3	1	0.003	0.045	RA's on TOP
	New York (JFK)	2	1:46:18	1	1	0	0.001	0.018	
	Philadelphia	5	7:51:34	19	27	4	0.001	0.036	RA's on Targets of Opportunity
	Newark (EWR)	1	1:58:06	5	8	0	0.001	0.065	
	Minneapolis (MSP)	2	4:30:11	14	1	0	0.0015	0.027	
	Dallas/Ft. Worth (DFW)	2	3:08:47	18	11	3	0.005	0.055	VMD opposite of actual miss; RA would have crossed altitude. See Summary of Results "Terminal Operations."
	Seattle (SEA)	1	2:14:10	6	16	1	0.003	0.027	
	San Francisco (SFO)	2	4:15:17	19	7	2	0.008	0.04	RA's on TOP
	Washington (DCA)	2	5:30:07	7	6	0	0.0015	0.026	
En Route	Atlantic City (ACY) to Jacksonville JAX (round trip)	1	3:52:09	0	0	0	0.0018	0.02	
	ACY to ATL via JAX (1 way)	1	2:51:41	0	1	0	0.001	0.008	
Surveil-lance	DFW-Los Angeles	1	2:57:15	0	0	0	0.005	0.0082	*** P_u MC = 0.91 P_u NMC = 0.84
	Los Angeles Basin	2	3:42:25	-	-	-	0.002	0.124	P_u MC = 0.8 P_u NMC = 0.78
	Bedford, MA	2	3:57:05	-	-	-	0.003	0.02	P_u MC = 0.82 P_u NMC = 0.83

*TA MC denotes Trafic Advisory; Mode C equipped intruder.
TA NMC denotes Traffic Advisory; non-Mode C equipped intruder
RA denotes Resolution Advisory

**Density is the number of aircraft per nmi^2.
***P_u MC denotes probability of update for Mode C aircraft; P_u NMC denotes probability of update for non-Mode C aircraft.

within the terminal airspace (including several approaches terminating in go-around procedures), en route refers to typical terminal to terminal operations, and surveillance refers to missions dedicated to testing certain aspects of surveillance. In such flights, CAS data were not recorded, only surveillance data.

Data in table 23 show each destination airport, the minimum and maximum traffic density observed, and the TCAS advisory frequency.

From the information in appendix B, several inferences can be made.

1. TCAS Reliability. Failure rate versus flight time can be determined.

2. Number and types of advisories to be expected in the various phases of flight.

3. Aircraft antenna configuration. Incidence of bad bearing flag indicates tracking on bottom antenna (omni) only.

4. Surveillance Performance. The transition matrix data coupled with the density plots show surveillance performance as a function of density.

5. CAS performance. The effectiveness of CAS modules, such as intruder on ground detection, in suppressing unnecessary traffic advisories is evaluated.

6. Potential for fakeout resolution advisories; if projected VMD (column F) is opposite sign of actual miss altitude (column G), a resolution advisory may have resulted in a "fakeout."

7. The improvement in TCAS performance as the program progressed, with the resolution of problems.

AIRCRAFT TRACKING - SURVEILLANCE. The surveillance function extracts and correlated replies from aircraft within TCAS' range gate. The replies are then passed along to CAS for tracking and threat detection. Surveillance must sort out valid replies from fruit and reflection of valid replies. The measures of surveillance performance developed in this evaluation are:

1. Probability of track (P_T), probability of update (P_u) versus density, Mode C/non-Mode C aircraft mix.

2. Coasting.

Item 1: P_T and P_u define "go-no go" surveillance performance, but are too broad when considering the impact on CAS. Therefore, coasting is added. When one or more surveillance update periods pass without receiving valid replies from aircraft in track, surveillance coasts a track by using predicted position as track update information. Coasting impacts CAS because no altitude update is received. CAS responds by decrementing the parameter "IFIRM" once for each coast (the maneuvering intruder case is excluded here). IFIRM has a range of zero to three; values of zero or one cause CAS to invoke its low firmness logic resolution logic (see TCAS MOPS). The implication of low firmness logic is that RA's are selected on vertical rate bounds established by TCAS rather than the intruder's actual trajectory.

Appendix B contains P_T and P_u density data from 15 cities. Included on each density plot is Mode C, non-Mode C, and total aircraft density. At the bottom of the page are the transition matricies for Mode C and non-Mode C aircraft tracks.

The matrices were developed on all aircraft within 10 nmi of the TCAS aircraft. Only tracks updated twice since formation were included in the data. The second filter reflects one criteria that surveillance tracks must satisfy before being established in CAS.

Selected missions were flown to test surveillance. A special data recording mode was used wherein only surveillance data are recorded. This mode is used to avoid data loss when the density increases.

Non-Mode C data gathering missions include Bedford, MA (see appendix B - missions 100483A&B and 010684), Norfolk, VA (mission 070683B), and Seattle, WA (mission 121283A). Mode C data were gathered in the Los Angeles Basin (missions 120983B and 121083), and in Dallas/Forth Worth (see mission 120883B). From these missions, a measure of P_T and P_u versus density, can be developed. Table 24 shows P_T and P_u for Mode C and non-Mode C traffic versus total density and traffic mix. (The parameters P_2 and P_3 will be discussed in the next section.)

Overall, the data in table 24 show that the parameters P_u and P_T degrade as density increases. However, one data point (marked by note 2) shows good tracking performance in instrument meteorological condition (IMC) even though the Mode C density is fairly high. Apparently ATC had terminal aircraft spaced to a point where synchronous garble was effectively eliminated. Thus, higher than expected update rates and a very low probability of track drop were observed for this day.

Item 2: By design, CAS invokes low firmness logic for IFIRM values of one or zero, which can be produced by coasting a track for two update periods or more. This discussion is not intended to imply that low firmness logic is not desirable; the point is, the logic was designed to resolve encounters against maneuvering intruders. Therefore, for purposes of surveillance performance analysis, a performance measure has been established as the probability of coasting for two successive scans. In table 24, the parameter P_2 defines this probability. Note that P_2 also defines the probability of coasting a track 40 percent of the time. For additional information regarding low firmness logic, see "Summation of the CAS Evaluation."

The parameter P_3 in table 24 defines the probability that an aircraft track will coast for three successive scans before being updated. At this rate, the vertical tracker degrades in its ability to estimate intruder vertical rates. Given intruder rates of 1500 feet per minute or more, TCAS will tend to estimate low until a valid update is received. This incorrect estimate could affect sense selection against an intruder. It is important to know if coast state three is being reached often. Therefore, P_3 provides a valuable measure of surveillance performance.

Table 24 shows very high track reliability (P_T) for densities up to 0.13 aircraft per nmi squared (equals 41 aircraft within 10 miles of TCAS). The table shows an aircraft mix of 0.08 (peak) Mode C aircraft, and 0.05 (peak) non-Mode C

TABLE 24. TCAS SURVEILLANCE PERFORMANCE VERSUS TRAFFIC DENSITY

Peak Density	Traffic Mix		Mode C				Non-Mode C		Note 3
	Mode C	Non-Mode C	P_u	P_T	P_2	P_3	P_u	P_T	
0.017	0.017	0.006	0.846	0.994	0.027	0.015	0.846	0.989	
0.024	0.014	0.011	0.9	0.998	0.016	0.007	0.877	0.995	
0.028	0.021	0.006	0.887	0.996	0.017	0.009	0.839	0.992	
0.034	0.019	0.01	0.895	0.998	0.017	0.006	0.879	0.995	
0.041	0.041	0.008	0.772	0.99	0.044	0.024	0.777	0.985	Note 1
0.046	0.044	0.01	0.727	0.986	0.053	0.032	0.731	0.983	Note 1
0.048	0.026	0.01	0.882	0.997	0.02	0.009	0.842	0.992	
0.054	0.054	0.01	0.891	0.998	0.017	0.007	0.824	0.993	Note 2
0.06	0.04	0.032	0.75	0.99	0.049	0.025	0.725	0.985	
0.130	0.08	0.05	0.72	0.987	0.056	0.03	0.665	0.979	

Notes: 1. Data recorded in missions 100483A & B. Surveillance evaluation missions to Bedford, MA.

2. *Data recorded in IMC conditions. See text.*

3. P_u denotes the probability of track update in successive update periods.

P_T denotes overall probability of maintaining surveillance tracks.

P_2 denotes the probability of coasting two successive update periods.

P_3 denotes the probability of coasting three successive update periods.

aircraft per nmi squared. At this density, the probability of coasting a track out is (1 - 0.987) 0.013 for Mode C, and (1-0.979) 0.021 for non-Mode C. The probability of being updated every scan (P_u) is 0.72 for Mode C, and 0.665 for non-Mode C. These lower values would lead one to expect higher values of P_2 and P_3. However, P_2 is 0.056 and P_3 is 0.03. Considering that the data in table 24 were accumulated over all aircraft tracks, the values of P_2 and P_3 are considered excellent.

In more typical densities TCAS is likely to encounter range from 0.034 to 0.06. In this range, the update and track probabilities (P_u and P_T) range from 0.895 to 0.75 (P_u) and 0.998 to 0.990 (P_T) for Mode C, and 0.879 to 0.725 (P_u) and 0.995 to 0.985 (P_T) for non-Mode C. P_2 and P_3 range from 0.017 to 0.049 (P_2) and 0.009 to 0.025 (P_3). These values suggest that surveillance was functioning well.

For an interpretation of the results in appendix B please see the section entitled "Summary of Results - Approaches."

OPERATIONAL EVALUATION.

Subject pilots from various airlines and airline organizations were invited to the Technical Center to fly the FAA B-727 with the TCAS avionics installed. Upon arriving the Technical Center the subjects received training and completed two flights. The flights consisted of an encounter flight in a sterile environment and a terminal area flight with targets of opportunity.

A total of 13 subject pilots participated in the operational evaluation. Two pilots completed their missions in July, and 11 pilots completed their missions in November (see Discussion - Operation Evaluation). A list of the participants' organizations is shown in table 25.

SUBJECT PILOT PARTICIPATION ENCOUNTER FLIGHTS. Each of the subject pilots except 5 and 6 were exposed to a minimum of six encounters. After each encounter, control of the aircraft was relinquished to the safety pilot (in the right seat) while an obsever questioned the subject pilot using a standard post-encounter form (figure 6).

TABLE 25. ORGANIZATIONS OF SUBJECT PILOTS THAT PARTICIPATED IN THE OPERATIONAL EVALUATION

Organization	Number of Pilots
American Airlines	2
FAA Office Atlanta Certification	1
Eastern Airlines (ALPA)	1
FAA	2
Piedmont Airlines	1
Republic Airlines	4
United Airlines	2

DATE ____________ **PILOT NUMBER** ____________

ENCOUNTER # ______ **TIME** ____________

EVENT	**NOTES**

PHASE: DEPARTURE CLIMB CRUISE DESCENT APPROACH HOLDING

PILOT AT CONTROLS: LEFT RIGHT VISIBILITY: VMC MARGINAL IMC

OVERALL RATING: +2 +1 0 -1 -2 ESSENTIAL INFO: RA TA ATC OTHER

USEFUL: YES NO NECESSARY: YES NO CORRECT: YES NO TIMELY: YES NO

COMMENTS:

+2 TCAS was vital to maintaining separation.
+1 TCAS assisted in maintaining separation.
0 TCAS has no effect upon safe separation.
-1 TCAS detracted from safety.
-2 TCAS created an unsafe condition.

INFLIGHT OBSERVER DATA FORM

FIGURE 6. INFLIGHT OBSERVER DATA FORM

The encounter flights were all conducted in Control Area Blue 24 between the altitudes of 12000 and 16000 feet. Coordination with the New York Center prevented targets of opportunity from creating a dangerous situation in the control area. Navigation of the B-727 and chase aircraft was accomplished using the Sea Isle and Waterloo Very High Frequency Omni Directional Range/Distance Measuring Equipment (VOR/DME) stations. All flights were conducted in VMC with greater than 5-mile visibility. One advantage to the large altitude block granted by New York was flexibility in conducting the encounters. On three occasions a cloud layer forced the encounter mission to be moved up or down to be in clear airspace. The encounters only require 1500 feet vertically, so a last minute adjustment for clouds was possible.

The subject pilots were given vectors and speed control and traffic advisories representative of terminal ATC procedures. In the first part of the operational evaluation (July), ATC function was provided by professional air traffic controllers located at the Center's terminal automation test facility (TATF). In the second part of the evaluation (November, December) the ATC function was provided by the safety pilot who communicated to the subject pilot over the aircraft intercom. Intercept instructions were issued to the chase aircraft by the safety pilot on the project RF, unheard by the subject pilot. A cockpit observer, noting pilot reactions, listened to the same audio as the subject pilot.

Overall, the ATC function provided by the safety pilot yielded better results; his vantage point made him better aware of the encounter development, enabling closer passage of the threat aircraft. Thus, more encounters resulted in positive RA's in part 2.

SUBJECT PILOT PARTICIPATION TERMINAL AREA FLIGHT. Each subject pilot flew a minimum of three approaches in a local terminal area. The type of approaches were dependent on the local weather conditions. All the approach flights except one were conducted in visual meteorological conditions (VMC). A cockpit observer took notes of pilot comments and response, but no dedicated questioning took place after an encounter due to workload.

Subject pilots were permitted to respond to TCAS as they desired. The safety pilot assisted the subject pilots with the TCAS information being displayed.

The approaches were made to 200 or 300 feet above the ground terminating in a missed approach procedure.

DELEGATION OF COCKPIT DUTIES. During all missions, a cockpit observer was positioned in the jump seat. The safety pilot always occupied the right seat.

Observer Duties - Encounter Flights. Whenever possible, The cockpit observer was required to:

1. Monitor in-cockpit TCAS performance, and to note anomalous TCAS display behavior, i.e., missing aural alerts, incorrect advisories, etc.

2. Copy ATC advisory against targets causing TCAS advisory.

3. Copy TCAS advisory sequence.

4. Monitor subject pilot response to TCAS information, e.g., note deviation from assigned altitude when following an RA, or maneuving based on TA's, etc.

5. Question subject pilots regarding the encounters using a standard post-encounter form (figure 6).

6. Assist the subject pilot, if necessary, in recalling sequences of events.

7. Summarize the events of the flight in report or memorandum.

8. Note automated terminal information system (ATIS) weather.

A technique suggested by Lincoln Laboratory, and found to work well, was to log the time of the conclusion of the encounter rather than the start. Time marking of the conclusions had two advantages: (a) often, in the rush of a TA and RA, the observer would forget to log the time, and (b) most incidents didn't have a clearly defined start point.

Observer Duties - Terminal Area Flights. En route and during the approaches, the observer had additional responsibilities:

1. Monitor in-cockpit TCAS performance.

2. Copy ATC traffic advisories.

3. Copy TCAS information.

4. Monitor subject pilot response to TCAS information.

5. Copy pilot comments regarding TCAS.

6. Pilot workload permitting, question the subject pilot about TCAS utility, correctness, and correlation with ATC advisories.

7. Summarize the day's events in a report or memorandum.

8. Note ATIS weather.

9. Note type of aircraft that caused TCAS advisories.

From the observer's reports, a summary report was written and distributed after each mission (see Related Documentation).

Safety Pilot Duties - All Flights. The safety pilot was also an integral part of the operational evaluation. His primary responsibility was the safety of all missions. He also acted as the copilot, assisting the pilot with such duties as ATC communications, power adjustments, and gear and flap settings. During all missions, the safety pilot assisted the subject pilots with visual search and acquisition of TCAS indicated traffic, and helped to answer any specific questions, either with TCAS or with the FAA aircraft. The safety pilot provided the ATC function for most of the encounter missions.

SUBJECT PILOT RATINGS ENCOUNTER FLIGHTS. Thirteen subject pilots flew a total of 78 encounters with a total of 93 targets. The breakdown of encounters experienced per subject pilot is: subject pilots 1 and 2 each saw nine encounters in part 1 (July). Subject pilots 3, 4, and 7 through 10 each saw six encounters each in part 2 (November). Subject pilots 11 through 13 each saw four out of six encounters (encounter numbers 1, 3, 4, 5) in part 2.

Figures 7 through 10 show the subject pilot ratings of TCAS performance based on their experience. Figures 8 and 9 show pilot responses from the inflight questionnaires in the area of usefulness, timeliness, necessity, correctness, and the source of information that helped to locate and sight the intruder. Figures 10 and 11 show the numerical ratings by encounter and by subject pilot. The rating scale is a 5 anchor scale extending from -2 to +2. The rating scale is explained in figure 6.

In figure 7, a "no" response was given in encounter 9 to the question: was the TCAS advisory "correct"? This "no", response was given as a result of a bearing error of two clock positons. The traffic and resolution advisory information was otherwise correct.

Figure 9 shows the pilot ratings by encounter; figure 10 shows the ratings by subject pilot. Both ratings are from observer data collected during part 2.

The overall averages from the pilot ratings were:

1. Was TCAS useful? Yes 96%; No = 4%

2. Was TCAS timely? Yes 74%; No = 20%; couldn't tell 6%

3. Was TCAS necessary? Yes = 68%; No = 32%

4. Was TCAS correct? Yes = 83%; No = 13%; couldn't tell = 4%

5. Essential Source of information? ATC = 34%; TA = 37%; RA = 8%; Visually = 13%; Did not acquire = 8%

Four encounters received negative ratings. These are:

1. Rating -1, encounter 1. Subject pilot number 11 was given a descend advisory on an intruder who passed below. The cause of this advisory was a rapid 300-foot vertical transition; -400, -300, -200-foot relative altitude, just before TCAS selected the resolution advisory. TCAS projected the target aircraft to be above at CPA, and issued a descend advisory. The advisory transitioned to a "TCAS abort."

2. Rating -2, encounter 1. Subject pilot 9 was given a descend advisory on traffic below. The advisory sequence was generated in the same manner as described in part 1 above. This encounter also terminated in a TCAS abort.

3. Rating -1, encounter 4. Subject pilot 6 was issued a descend advisory on traffic that was above, descending, and, ultimately, passed below. TCAS made the proper selection and the subject pilot felt he could have cleared the traffic. The safety pilot knew that the chase aircraft was supposed to pass below, per a planned scenario, and prevented the subject pilot from lowering the aircraft. This encounter terminated in a TCAS invalid.

Encounter No.	Useful Yes	Useful No	Timely Yes	Timely No	Necessary Yes	Necessary No	Correct Yes	Correct No	Pilot's Rating -2	-1	0	+1	+2
1	1	0	1	0	1	0	1	0					1
2	1	0	1	0	1	0	1	0					-
3	1	0	1	0	1	0	1	0					1
4	1	0	1	0	1	0	1	0					1
5	-	-	-	-	-	-	-	-					1
6	2	0	2	0	2	0	2	0				1	
7	1	0	1	0	1	0	1	0				-	
8	------	------	------	------	------	------	------	------	------	------	------	------	------
9	-	-	0	-	-	-	0	1					1

Note: Dashes indicate no rating given.

FIGURE 7. INFLIGHT QUESTIONNAIRE RESPONSES FROM PART 1 (SUBJECT PILOTS 1 AND 2)

Encounter	Useful Yes	Useful No	Timely[2] Yes	Timely[2] No	Necessary Yes	Necessary No	Correct Yes	Correct No	Couldn't Tell	Essential Information[1] ATC	TA	RA	Vis.	Did Not Acquire
1	8	1	7	1	5	4	4	3	2	1	4	2	1	1
2	6	0	4	1	3	3	6	0	0	4	2	0	0	0
3	8	0	8	0	6	2	8	0	0	2	6	0	0	0
4	8	1	6	3	6	3	7	2	0	4	3	0	2	0
5	9	0	7	2	8	1	8	1	0	6	6	3	1	2
6	6	0	3	2	4	2	6	0	0	4	2	0	4	2

Note: 1. Essential Information means information used to obtain target visually.
2. Three responses to this question were "couldn't tell."

FIGURE 8. INFLIGHT QUESTIONNAIRE RESPONSES FROM PART 2 FROM PART 2 (SUBJECT PILOTS 3 THROUGH 13)

Overall Rating by Encounter

	Encounter					
	1	2	3	4	5	6
TCAS Was Vital To Maintaining Separation (+2)	3	2	3	4	4	2
TCAS Assisted in Maintaining Separation (+1)	3	2	5	2	5	2
TCAS Had No Effect (0)	1	2	0	1	0	2
TCAS Detracted From Safety (-1)	1	0	0	2	0	0
TCAS Created an Unsafe Condition (-2)	1	0	0	0	0	0
Average	0.7	1.0	1.4	0.9	1.4	1.0

FIGURE 9. PILOT RATINGS BY ENCOUNTER

Overall Rating by Subject

	Subject Pilot								
Overall Rating	3	4*	7	8	9	10	11	12	13
+2	4	2	4	2	4	2	0	0	1
+1	2	3	2	1	1	3	2	3	2
0	0	1	0	1	1	0	1	1	0
-1	0	0	0	1	0	0	1	0	1
-2	0	0	0	0	0	1	0	0	0
Average	1.7	1.2	1.7	0.8	1.5	0.8	0.3	0.8	0.8

Overall Average 1.0

*Subject pilots 5 and 6 did not complete an encounter mission.

FIGURE 10. RATINGS BY SUBJECT PILOTS-OPERATIONAL EVALUATION PART 2

4. Rating -1, encounter 4. Subject pilot 9 was issued a resolution advisory, but the traffic presentation showed no bearing data. The loss of bearing caused the pilot to work harder and actually detracted from the visual scene outside the cockpit. The actual rating given by the pilot was 0/-1.

SUBJECT PILOT OPINION - GENERAL COMMENTS. After having completed their scheduled missions, the subject pilots completed post-flight questionnaires. The results of the questionnaires, along with observer notes and general comments are summarized below. (The questionnaire responses are contained in the summary reports for each flight.)

Comments Regarding the IVSI. Twelve out of 13 subject pilots stated that the IVSI climb and descend arrows should be changed from red to green. The most consistent comment was fly to red is inconsistent with the pilot's instincts. One pilot stated that red was the proper color for the arrows. He said that the red was more compelling than green.

Four subject pilots stated that the IVSI was out of the primary scan of the pilot, especially in VMC when the pilot's eyes are outside the cockpit. These pilots also commented that the audio alerts are far more effective in conveying the resolution advisory. (Note: The modified IVSI used for TCAS was located in the primary instrument cutout, and was fully operational.)

Comments Regarding the Modified Weather Radar Display. All subject pilots agreed that the traffic advisory display was better than ATC for traffic information. The most valuable information was bearing, followed by range, then relative altitude. Relative altitude was very useful in confirming intruder status after visual acquisition. (Note: In IMC, the most valuable traffic information was relative altitude then range.)

The altitude trend arrow was very helpful in altitude crossing encounters, but it was not enough to make the pilots realize that an altitude crossing was taking place. When the pilots saw such encounters, they followed the RA and only realized after the intruder passed below that they crossed altitudes. No pilot refused to follow the RA based on his visual scene.

Four pilots made the comment that the display symbology was "very good and easily understood." The remaining pilots stated that the display "was hard to see in it's present location." Virtually all the pilots stated that the red is hard to see. Ten out of 13 pilots stated that sunlight was a problem; in direct sun, the display was unreadable. (A small 2-inch high shield was made of cardboard and placed around the display face for sun shielding.)

During the operational evaluation, one of the chase aircraft showed as no bearing (NO BRG) on the display for much of the advisory time. The NO BRG presentation was rated low via every possible means. Aircraft shown as NO BRG, especially in proximate or traffic advisory status, exaggerate the workload on the pilot considerably. When the aircraft causing the NO BRG advisory was visible in front, the subject pilots were able to acquire using a normal scan prompted by the advisory. However, when the threat was not visible, the advisory became distracting.

One pilot stated that the range ring asterisks obliterated the altitude code over a target symbol when the two were overlapped.

Non-Mode C traffic advisories were useful to all the pilots except when NO BRG data were presented. Since range and relative altitude were not available, the pilots tended to abbreviate their visual search, and two subjects commented that they ignored them totally. When NO BRG non-Mode C advisories were accompanied by ATC advisories, the pilots tended to concentrate their search in the ATC indicated traffic location prompted by the TA.

A general comment was made by one of the inflight observers: the subject pilots quickly became acclimated to the traffic advisory display. However, in learning the display, there is no substitute for experience. Even the video tape training was not enough to convey the full impact of the display.

Comments Regarding the Aural Advisories. All pilots stated that the aural alerts were effective in capturing the pilot's attention. Especially effective was the resolution advisory sequence; four of the subject pilots used only the aurals, and did not look at the IVSI, when following resolution advisories. An operational problem was discovered when, during several encounters, these subject pilots attempted to respond in the wrong direction. They did so because the words "don't" and "limit" proceeding the word "descend" were not perceived. Instead of "don't (or) limit descend" the subject pilots perceived "descend." Furthermore, those four subject pilots that flew by the aurals did not cancel the audio, which repeats once per second, and they simply continued to miss the words "don't" or "limit."

The C chord and word "traffic" used for TA annunciation were conspicuous in less busy periods, e.g., level flight, but were not obtrusive during busier periods such as approaches. The subject pilots never rated TCAS a distraction even though as many as three traffic advisories occurred during a single approach and go-around. All the subject pilots quickly recognized intruders who were on the ground by reading the relative altitude tags on the display. These intruders were considered a nuisance and eight of the subject pilots said they must be eliminated.

Comments Regarding the TCAS Controls. All subject pilots except one said that the TCAS tracks switch position should be detented. Five out of 13 pilots said adjustable limits on the range of the all-proximity traffic display would be very useful.

The TCAS caution warning switches were ineffective in capturing the pilot's attention (the intent of the lighted TCAS switch is the same as the light in the Boeing's master caution warning system, (appendix E, item 1)). The switch used in the FAA B-727 is a single lamp design which is not bright enough in daylight. A dual lamp design is available. The single lamp design was bright enough in night flying.

The switch was functionally effective as 9 out of 13 pilots experimented with cancelling the aural advisories.

Comments Regarding TCAS Advisories. Every subject pilot agreed that TCAS non-Mode C traffic advisories are useful, providing the same or more information than an ATC advisory of altitude unknown traffic. Non-Mode C advisories are most useful when the bearing presentation is given. When bearing is unavailable, the workload associated with the TA increases dramatically because bearing and relative altitude information is not available to the pilot. (The percentage of time that bearing loss occurs on TA's is indicated under "Antenna Configuration.")

TCAS resolution advisories were generally accepted by the subject pilots, but there were exceptions. All of the encounters were planned with horizontal and vertical buffers (0.25 nmi and 300 feet) to ensure safety, and no resolution was mandatory. The subject pilots were not made aware of these spacings and were told to respond consistent with the planned Piedmont procedures - clear the airspace in the direction of the move and follow the advisory. Figure 11 is a graph showing pilot responses to resolution advisories.

Several encounters, especially those involving threat aircraft above and below, were resolved by turns only after visual acquisition of both aircraft. When the subject pilots realized the "sandwich" was developing, they consistently turned slightly to avoid directly overflying or underflying the target aircraft.

In several encounters, subject pilots did not follow the resolution advisories. If the pilots judged that the intruder would pass safely, they did not move the aircraft.

Based on the Technical Center's experience with TCAS, the necessity of resolution advisories are mandatory.

The primary responsibility of a pilot in collision avoidance is see and avoid. This activity is easily accomplished with threats which are visible. However, even light haze can dramatically reduce the range of target visibility. Technical Center test pilots and two subject pilots were observed to disregard traffic advisories when no visual acquisition was made. No pilot disregarded the resolution advisories however. Even during the busiest periods, the pilot was compelled to at least assess the situation and then make a decision regarding his required action.

Subject pilots experienced difficulty with two types of TCAS resolution advisories: altitude crossing and TCAS invalid. Altitude crossing geometries were always rated "necessary" by the subject pilots because only after the encounter terminated did the pilots realize they were advised to cross altitudes. When the subject pilots maneuvered the aircraft in response to the resolution advisories, they were doing so without realizing they were crossing altitudes. Five of the pilots said the vertical rate arrow on the traffic display was very helpful in accepting the advisory, but the arrow is not dedicated to altitude crossing maneuvers and, thus, doesn't provide the necessary information.

The problem with pilots simply "obeying" resolution advisories in altitude crossing geometries is that they set themselves up for a "fakeout" (appendix E, item 1) if the intruder levels off before crossing altitude. The resolution advisory is then invalid because the advised direction of motion would decrease rather then increase vertical separation. When TCAS computes its error, it issues a TCAS invalid advisory. During the operational evaluation three subject pilots received TCAS invalid advisories. One pilot felt the original RA was correct but was instructed not to maneuver by the safety pilot because response would have violated the planned scenario. The other pilots had the intruder in sight through the entire encounter and did not follow the advisory. The incorrect advisory was followed by a TCAS abort 10 to 15 seconds later. The abort advisory left the pilot confused, but because he saw the intruder and

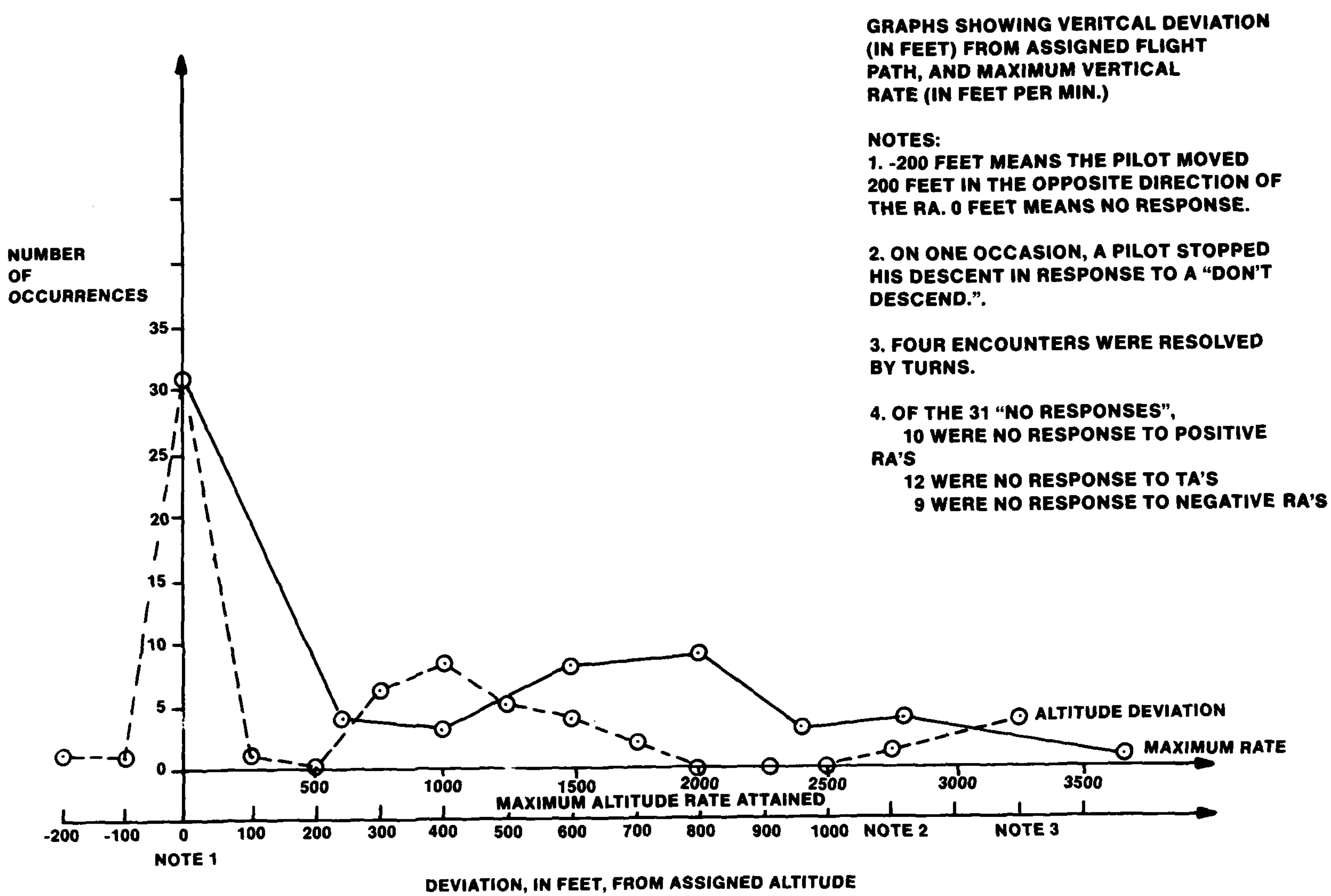


FIGURE 11. PILOT RESPONSES TO ADVISORIES

didn't follow the advisory, in his mind a dangerous situation was not created. The abort advisory then made the pilots feel that they should "abort" what they were doing, even though the conflict was being resolved safely. The problem with the incorrect advisory was futher compounded by the lateness of the abort advisory. The pilot quickly realized the first advisory was incorrect, but when the TCAS abort (with the European siren) occurred 10 to 15 seconds later, the pilot felt compelled to take action even though he was not sure what to do. Had the abort occurred sooner the pilot may have connected it with the incorrect RA instead of perceiving it as another RA.

TCAS Mode C traffic advisories were rated very high in value by all pilots in alerting the position of threatening aircraft. No pilots manuevered based solely on TA information. Pilots did prepare for maneuvering (e.g., disable the autopilot) if they visually acquired the threat.

Comments Regarding Workload. The subject pilots were asked if TCAS increased their flight deck workload. Seven said increase slightly, six said decrease slightly. (The scale was a 7 anchor rating scale with the two responses above located either side of the mean "No change" response.) No subject said workload was a problem. Several subject pilots expressed concern when TCAS issued positive resolution advisories on intruders 500 feet away vertically (VFR spacing) at altitudes less than 10000 feet (m.s.l.). These pilots felt such advisories were unnecessary.

Comments Regarding ATC Integration. All of the subject pilots said that TCAS was completely compatible with ATC. Also, no pilot felt constrained to adhere to previous ATC clearances in the event of an RA because TCAS was establishing the cockpit priorities. Finally, all pilots agreed that TCAS was better able to point out traffic of true interest even though they recognized the fact that ATC had the a prior knowlege of the intentions of the threatening aircraft. For example, an aircraft on a parallel approach caused a TCAS TA which was called by ATC as "no factor."

Comments Regarding Pilot Procedures. All pilots expressed concern at the lack of a regimented procedure to follow in the event of TCAS abort.

The pilots agreed with all except one of the proposed procedures for the Piedmont evaluation. The exceptional procedure states: Clear the airspace in the direction of the resolution advisories and move the aircraft. Four subject pilots said that they would move the aircraft whether they were able to visually clear the airspace or not. Eight of the subject pilots said they would move the aircraft whether they were able to see the intruder or not. Each of the responses was followed by a comment such as: the current airspace is dangerous; the chances are excellent that airspace in the direction of the move will be clear. Two subject pilots stated that they probably would not move the aircraft if they saw the intruder (and could see he would pass safely). All subjects said they would not follow the advisory if other information (e.g., visual scene) precluded the TCAS information. This statement was corroborated by the pilot's actions during the operational evalution.

Comments Regarding the FAA Training Procedure and Test Conduct. The subject pilots were asked to rate their experience at the Technical Center. All of the pilots commented favorably about the program. Eight of the pilots rated the training "good," the other four criticized the video tape training as containing too much titling dialogue.

OPERATIONAL EVALUATION INDUSTRY REVIEW. On December 1 and 2, a review of the operational evaluation was held at the Technical Center. The attendees included representatives from the aviation community including several subject pilots who participated in the operational evaluation, as well as the FAA and their supporting organizations.

The bulk of the meeting was discussion focused on TCAS deficiencies observed by the subject pilots, and, at times, rather sharp criticism was made against the prototype TCAS. The review was concluded and the outcome was a list of 13 deficiencies that required resolution.

Table 26 lists the 13 deficiencies, and the status as of May, 1984.

NATIONAL DEMONSTRATION TOUR.

Overall, the tour was an excellent success, marred only by one visible TCAS problem and two less conspicuous problems. The visible problem occurred in Dallas/Fort Worth: a bearing indication which was initally presented at 11 o'clock but then jumped to 1 o'clock at an intruder range of 2 miles. The two less conspicuous problems were: (1) an early morning startup problem in Minneapolis, which corrected itself after the aircraft cabin warmed up; and (2) repeated self-test failures in the data gathering flight in the Los Angeles Basin.

The bearing jump was observed by visitors observing the television monitor in the cabin, and by visitors observing the flight in the cockpit.

Two problems have been resolved as of April 1984; the problem of self-test failures in the Los Angeles Basin is still unresolved.

Flight data from the tour were processed in the manner of the data from the approach missions. Appendix B contains the data summaries.

SUPPRESSION OF UNWANTED ADVISORIES. Multipath rejection functions as designed. The algorithm can be confounded, however, in sustained periods of multipath. If few or no valid replies are received from the target aircraft, TCAS will eventually use multipath replies to extend the intruder track. Such tracks can progress to impact the display status. This condition was not a problem, however, because long periods of multipath nearly always resulted from ground bounce. The geometries involved mandate the presence of a threatning aircraft in the vicinity.

Intruders on the ground can create an unwanted nuisance. The original intruder o ground logic was not completely effective in suppressing ground alerts. In December 1983, the Technical Center proposed a modification to improve the algorithm (reference appendix B). The modification was implemented and verified as of the February acceptance test at the factory. Typically, 20 percent fewer advisories are generated with the new parameter.

TABLE 26. TCAS DEFICIENCES DEFINED IN THE OPERATIONAL EVALUATION REVIEW AND CURRENT STATUS

1. Voice quality/use of "limit" and "don't" Preceding the Spoken Words "Climb" or "Descend."

Action: Changed spoken phrase to "limit vertical rate" in all speed limit RA's.

2. *CRT Washout Caused by Direct Sunlight.*

Action: Tilt the display slightly.

3. Loss of Bearing. Intermittant loss of bearing during planned encounters.

Action: This problem was mainly due to FAA aircraft tracking (see item 5). However, to determine if the problem was universal, an examination was conducted. The current TCAS antenna configuration will display no bearing if TCAS is tracking a low aircraft on the bottom omniantenna only. ACT-140 studied the flight data from 63.25 hours of data from typical airline operations (appendix B) and found the bearing invalid approximately 5.4% of the total advisory display time. This represents an average 1.5 out of every 30 seconds of displayed advisories. (See also Summary of Results - antenna configuration.)

4. Audio Alerts Missing in Several Cases of RA Sequences.

Action: Coding error was Corrected in Trouble Report No. 4.

5. Transponder/Target Aircraft Problem. The test aircraft used in the operational evaluation were very poorly tracked by TCAS.

Action: Several factors contributed to the poor tracking, the most prominent being a transponder sensitivity to whisper-shout interrogations. The Technical Center and Lincoln Laboratory are jointly studying the problem. Note that the performance observed in the operational evaluation has improved since the repairs to the antenna and receivers in response to item 12 of this table (see also CAS Validation - Certification Testing, both systems.)

6. Mode C low Altitude (Newark). A TA was generated on an aircraft 2900 feet low.

Action: Coding error was corrected in trouble report No. 8.

7. On Ground Altitude Parameter. TA's against aircraft on the airport surface were observed by subject pilots. This deficiency was sharply criticized.

Action: ACT-140 studied appendix B data from airline operations and determined a new altitude threshold for rejecting the nuisance alerts. This operational data included data from the national tour so the new parameter accounts for terrain variations at varying elevations. Dalmo Victor installed the new parameter in April 1984.

TABLE 26. TCAS DEFICIENCES DEFINED IN THE OPERATIONAL EVALUATION REVIEW AND CURRENT STATUS (CONTINUED)

8. Symbology/Color/Location of CRT. Subject pilots critized the use of the color red and symbol size of alphanumerics, especially in the "no bearing" table.

Action: The color was not changed, the symbol size was increased slightly.

9. Late acquisitions of Target Aircraft (apparently beyond the problem with the transponder in the test aircraft).

Action: Data from certification testing was reviewed; no advisory times were less than 20 seconds. Typically, the 25 to 40 seconds advisory time was provided. Also data from appendix B show the following average TA advisory times (seconds before CPA) for targets of opportunity:

Performance level 4: 24.09 seconds
Performance level 5: 34.05 seconds
Performance level 6: 44.05 seconds

(See also CAS Validation - Certification Testing, both systems.

10. Caution/Warning Lighted Switches. Single bulb design not highly visible, and orientation of switches in N-40 was not facing the pilot.

Action: ACT-140 has received 10 switches that use two 28 volt lamps each. These switches are available for the Piedmont installation and are superior to the single bulb switches currently in use at the Technical Center.

11. Symbol Overlap. Some cluttering of the display occurs due to aircraft symbols interferring with other symbols and the display legend.

Action: None.

12. Bearing Jumps. Displayed intruder bearing was jumping in mirror image fashion about the cardinal axes. This deficiency drew sharp criticism in the operational review meeting.

Action: Two of the antennas supplied by Dalmo Victor demonstrated a degradation in their radiation patterns. In addition, two of the receivers developed noise in their power supplies resulting in an intermittant bias in one or two receiver channels. The problem was resolved by February 1984 and the resolution was the result of a combined effort by Lincoln Laboratory, Dalmo Victor, and the Technical Center.

13. Performance of the System with Abort Advisory.

Action: Lincoln Laboratory and the MITRE Corporation were tasked to analyze the aborts during the Center's operational evaluation and recommend alternative alerting methodology.

Based on available data (e.g., appendix B), ACT-140 concluded that the items in table 26, except for item 13, were all resolved.

Only Mode C intruders are detected by the intruder on ground logic. However, the incidence of non-Mode C TCAS was typically one per approach in VMC. The operational evaluation concluded that the alarm rate wasn't excessive.

DRY RUN CERTIFICATION TEST.

Overall, TCAS performance was excellent in these tests. Bearing accuracy, especially off the nose, was very accurate and stable. Tracking was good, providing the advisory times per design, and all resolution advisories were correct and within the design bounds (see also Flight Test, CAS Validation).

No outstanding problems remained as a result of these tests.

SUMMARY OF RESULTS

ENGINEERING EVALUATION.

BENCH TESTS. The TCAS prototypes showed stability in the hardware subsystems including transmitter, W/S attenuator, reply video processor, and aircraft interface sensing.

The prototypes showed instability in the receivers and antenna. The receivers showed some degradation in sensitivity. Tables 4 and 5 show a 3 dB degradation in the 0° receiver in SN01 TCAS. The receivers in SN02 TCAS are 4 dB weaker overall than SN01 TCAS. Because all receivers in SN02 are balanced, AOA is not affected. Weak targets will not track as well. The RF link margin is 6 dB, was not violated, so the receiver problem did not have a significant impact in aircraft tracking.

The antenna instability will be described in the "STATIC TESTS" section.

STATIC TESTS. SN05 receiver antenna patterns were measured in static tests at the Center and were found to have changed from the baseline factory measurements. The cause of the change was stress induced dielectric alteration.

SN02, SN04, and SN06 receiver patterns were measured and found to be stable and able to withstand temperature, humidity, and pressure stresses. The radiation patterns for these antennas were correct (appendix A). SN04 antenna is installed on the FAA B-727, the SN06 was shipped to Piedmont. SN02 antenna exhibited a VSWR problem which was corrected.

FLIGHT TESTS. The CAS logic implementation has been tested, repaired, modified, and retested. All outstanding problems in subsystems including threat detection and resolution, aircraft tracking, and suppression of unwanted advisories have been resolved.

Threat Detection and Resolution. A total of seven logic errors were detected during the evaluation period. These errors (listed in table 18) were reported to Dalmo Victor and software corrections were made. All corrections were completed by September 1, 1984.

Aircraft Tracking. The surveillance to CAS transition of aircraft tracks is handled proplerly, and subsequent tracking is performed correctly.

OPERATIONAL EVALUATION.

The cockpit configuration is acceptable for a Piedmont installation. Some results did come from the evaluation, however, that dictate that the current display configuration is not final. The summaries in the following paragraphs apply to VMC operation.

TCAS DISPLAYS.

IVSI. The IVSI is not in the pilot's visual scan during an encounter because after a quick inspection of the TA display, all eyes are outside either trying to find or maintain visual contact on the intruder.

For this reason, the prescribed 1500 fpm vertical rates were seldom attained in responding to resolution advisories. Typical rates attained were closer to 2000 fpm. In order to safely clear the intruder aircraft, the subject pilots moved the aircraft based soley on the visual scene. ACT-140's impression is that this method worked very well.

Traffic Advisory Display. TCAS range, bearing, and relative altitude information were displayed on the weather radar display. The display format is efficient and the color coding effective. The display has two difficiencies: the color red is hard to see and the display is not readable in direct sunlight. A lesser problem is symbol size, causing the pilot to strain to read the altitude tags. ACT-140's understanding is that the display location in the Piedmont aircraft will assuage the sunlight deficiency and symbol size problem.

Overall, the TA display was rated as acceptable during the operational evaluation.

TCAS Aurals. Initially, the RA messages "don't climb (descend)" or "limit climb (descend)" were spoken by TCAS. These were changed to "limit vertical rate" spoken by TCAS when several pilots missed the "don't" or "limit" prefix.

TCAS Controls. The spring loaded TCAS tracks switch should be detented in the "TRACKS" position in accordance with subject pilot opinion.

TCAS Procedures. Subject pilots said that they would move the aircraft, whether they were able to see the intruder or not, because the present altitude is resulting in an RA. The other procedures, except the TCAS invalid, were acceptable.

All the subject pilots, as well as Center test pilots, were concerned about the TCAS invalid advisory, saying that the pilot should be given some direction.

ATC Interaction. Most pilots reported that TCAS and ATC complemented very well. Typically, TCAS issued traffic advisories within 5 seconds of ATC traffic calls.

No pilot reported any problems integrating TCAS with ATC.

TERMINAL OPERATIONS.

The approach data are contained in appendix B.

ALARM RATES. These alarms include valid advisories not eliminated by the Piedmont supression logic.

Traffic Advisories. Typically, 1 to 1.5 traffic advisories occurred per approach and depart sequence. Totals are 102 mode C advisories and 86 non-Mode C advisories, resulting in a mean of 1.6 Mode C TA's and 1.3 non-Mode C TA's per hour in terminal operations.

Resolution Advisories. In 63.26 hours of flying approaches, 12 RA's were generated, for a mean of 1 RA every 5.27 hours.

POTENTIAL FOR FAKEOUT (TCAS INVALID). In 200 valid traffic advisories, 1 was a potential fakeout. No RA was generated, but had there been, an invalid may have occurred because TCAS projected the vertically accelerating intruder to be 800 feet below at CPA, but the intruder actually passed 400 feet above. This event occurred in mission No. 120883B.

INCIDENTS WITH TARGETS OF OPPORTUNITY. TCAS generated 200 advisories including 12 resolution advisories and 188 Mode C and non-Mode C traffic advisories. The actual miss distances against these aircraft are shown in table 27.

Of the 44 encounters within 3000 feet, 25 were non-Mode C intruders and 19 were Mode C intruders. A point of note: all three aircraft that passed within 1000 feet of N-40 were Mode C equipped. The closest intruder was 182 feet (0.03 nmi); the incident ocurred in Minneapolis on December 7, 1983 (mission No. 120783).

SURVEILLANCE PERFORMANCE. See appendix B for the transition matricies and associated density plots for each approach mission.

TCAS IMPROVEMENT. Scanning appendix B, the number of problems such as TCAS failures or traffic advisories that should be suppressed, diminishes as time passses. In general, the missions become more successful.

TCAS RELIABILITY. In 306 hours, six failures were suffered, resulting in an MTBF of 51 hours.

In the period May 1983 to June 1, 1984 the two systems suffered six failures:

1. Three transmitter failures (two driver failures, one W/S failure).

2. One RS232 bus failure.

3. Two display control unit (DCU) failures. These units drive the TCAS lights in the IVSI.

4. Failures in three antennas (one self-test failure, 2 pattern shifts).

The TCAS prototypes SN01 and SN02 accured the time shown in table 28.

TABLE 27. ACTUAL MISS DISTANCE FROM TARGETS OF OPPORTUNITY

Actual Miss Distance (Slant Range in Feet)						
<500	<1000	<1500	<2000	<2500	<3000	>3000
1	2	14	9	13	5	all others

TABLE 28. TCAS OPERATING TIME

Total Flight Time: 141 hours, 5 minutes, 12 seconds.

Engineering Evaluation - SN01: 34 hours, 4 minutes, 11 seconds
Engineering Evaluation - SN02: 24 hours, 6 minutes, 34 seconds
Operational Evaluation - SN02: 25 hours, 1 minute, 14 seconds
National Tour - SN02: 29 hours, 9 minutes, 12 seconds
Demonstration Flights SN01: 1 hour, 39 minutes
Demonstration Flights SN02: 4 hours, 1 minute
Antenna Testing: 16 hours, 2 minutes, 33 seconds
Dry Run Certification Testing: 7 hours, 1 minute, 48 seconds

Total Ramp and Bench Time (includes factory acceptance tests): 165 hours

SN01 (approximate) 75 hours
SN02 (approximate) 90 hours

Total Time Flying Approaches: 63 hours, 15 minues, 49 seconds
Total Time Flying Encounters: 49 hours, 36 minutes, 58 seconds
Total TCAS Service Time (approximate): 306 hours

Installation and Modification Time (approximate): 240 hours

ANTENNA CONFIGURATION. In 63 hours of flying approaches, traffic advisories were displayed a total of 4531 seconds. The intruder's bearing was invalid ("NO BRG" tabular display) a total of 247 seconds for an average of 5.4 percent of the total advisory display time. Invalid bearing results when an intruder is being tracked only on the bottom (omnidirectional) antenna.

CONCLUSIONS

1. The Dalmo Victor Traffic Alert and Collision Avoidance System (TCAS) prototype is acceptable for use during the Piedmont phase II evaluation:

a. The hardware reliability of the prototype has been demonstrated after a series of "infant failures," e.g., transmitter failure, were repaired.

b. Pilot acceptability of the display configuration is generally good.

c. The antenna configuration yields adequate surveillance and bearing data of intruder aircraft.

d. The detection and resolution of threats is amenable to pilots and doesn't result in excessive workload.

e. False and nuisance advisory suppression is adequate.

2. While the current minimum TCAS II configuration is acceptable for gathering operational data, the following deficiencies need to be resolved prior to widespread deployment:

a. The color red on the traffic advisory display is difficult to see.

b. Generation of positive resolution advisories against Visual Flight Rules (VFR) separated aircraft.

c. A viable procedure to follow given a TCAS invalid advisory has to be determined.

d. Advisories against intruders on the ground who are non-Mode C or Mode C should be suppressed.

3. Resolution of threats when track firmness is low can cause a departure from the expected TCAS response, e.g., positive resolution advisories (RA's) against VFR separated aircraft. Low track firmness results from surveillance track coasting and altitude transitions by the intruder. The interaction of the low firmness CAS logic with "real word" surveillance conditions needs to be further understood.

RECOMMENDATIONS

1. Valuable system data can be derived from Piedmont phase II. This report recommends that the program commence immediately.

2. Coincident with Piedmont, studies should be performed to resolve two remaining deficiencies in the minimum TCAS II configuration:

a. Eliminate positive resolution advisories against Visual Flight Rules (VFR) separated aircraft where possible.

b. Develop techniques to eliminate advisories against intruders on the ground.

3. Piedmont flight data analysis should include the monitoring of the following parameters as a minimum:

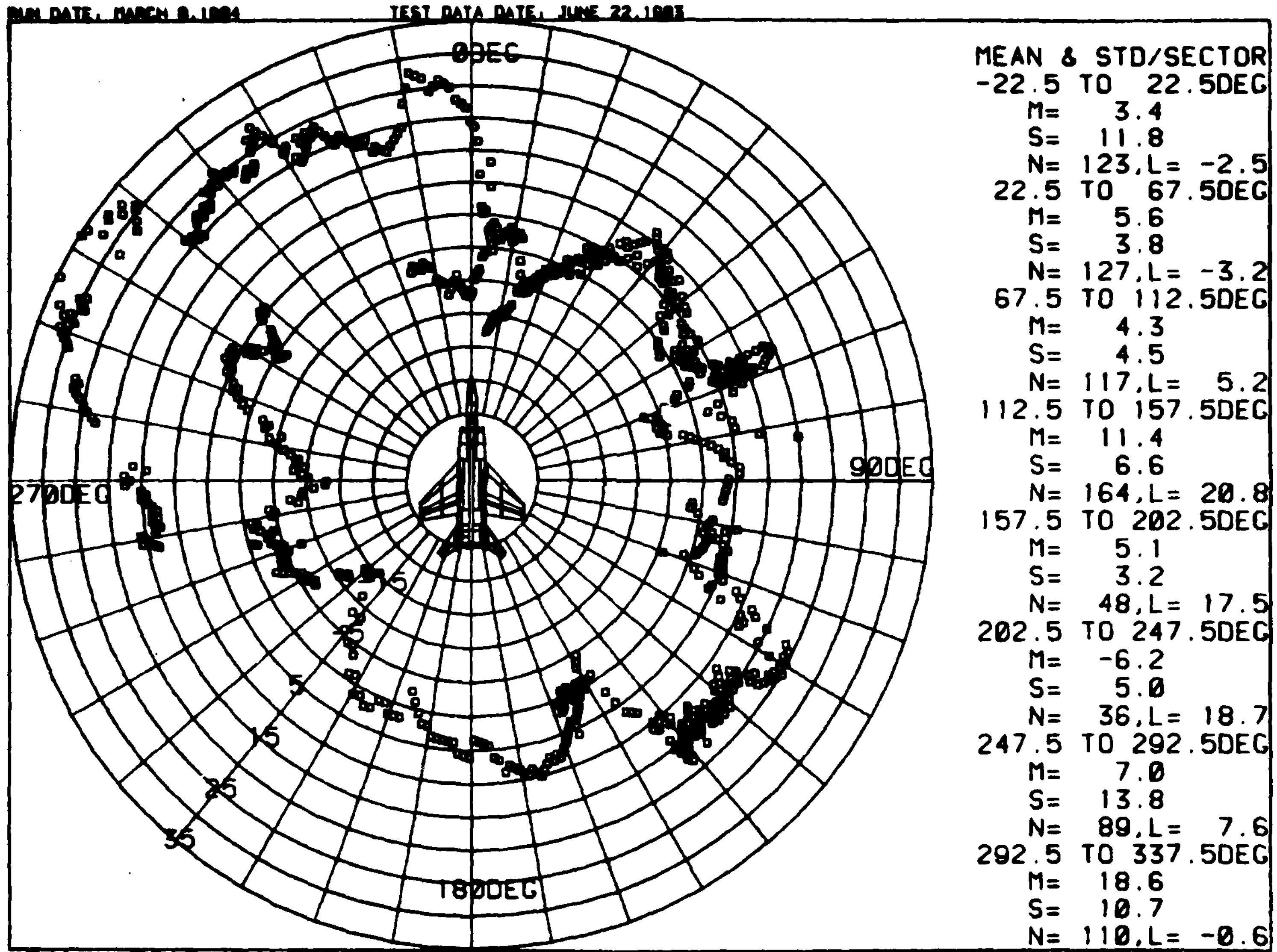
a. Surveillance parameters, probability of track (P_T), probability of update (P_u), probability of coasting two scans (P_2), probability of coasting three scans (P_3).

b. Percentage of time IFIRM is zero or one during traffic alerts (TA's) and/or resolution advisories (RA's).

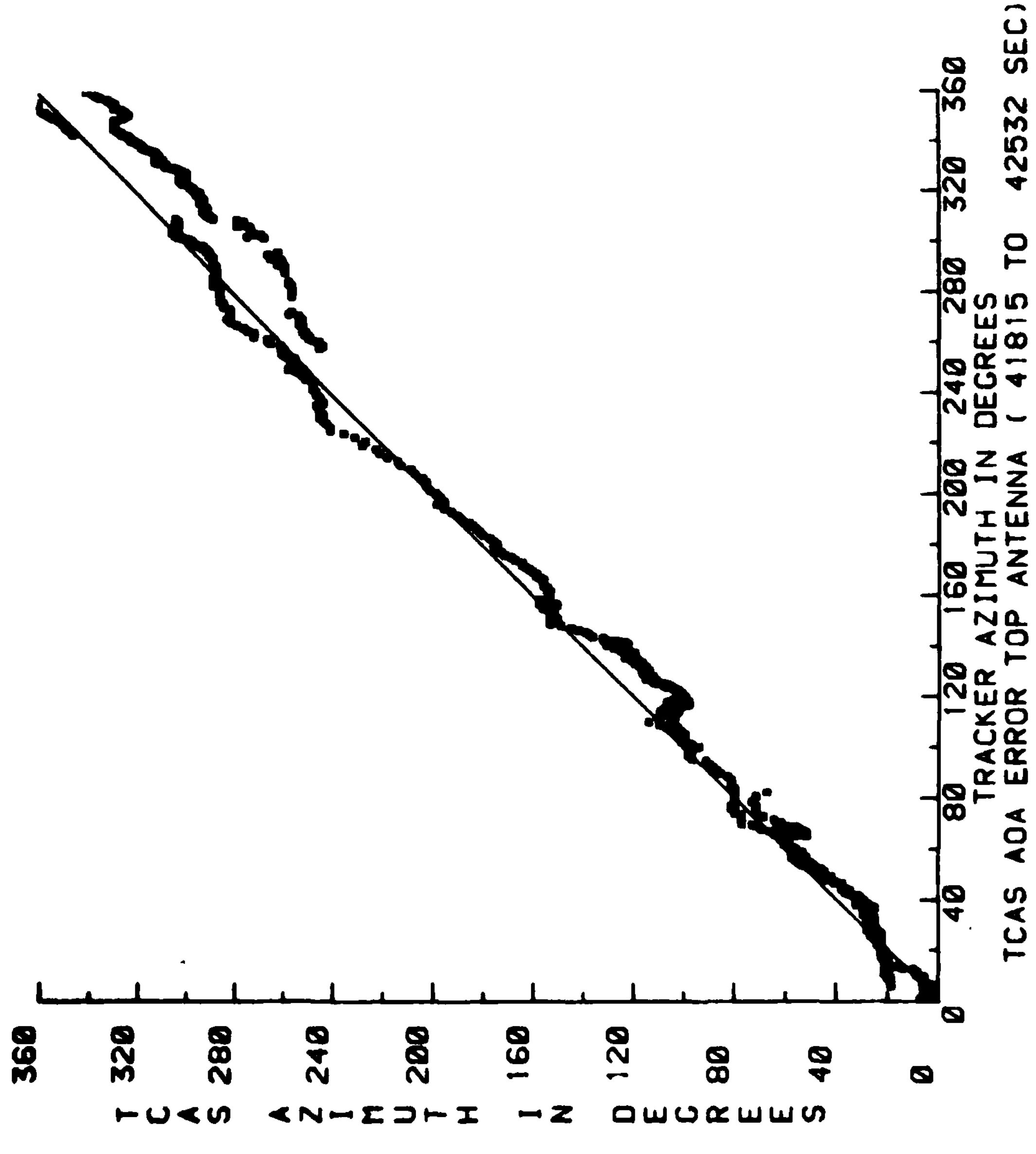
c. Number of RA's selected on low firmness.

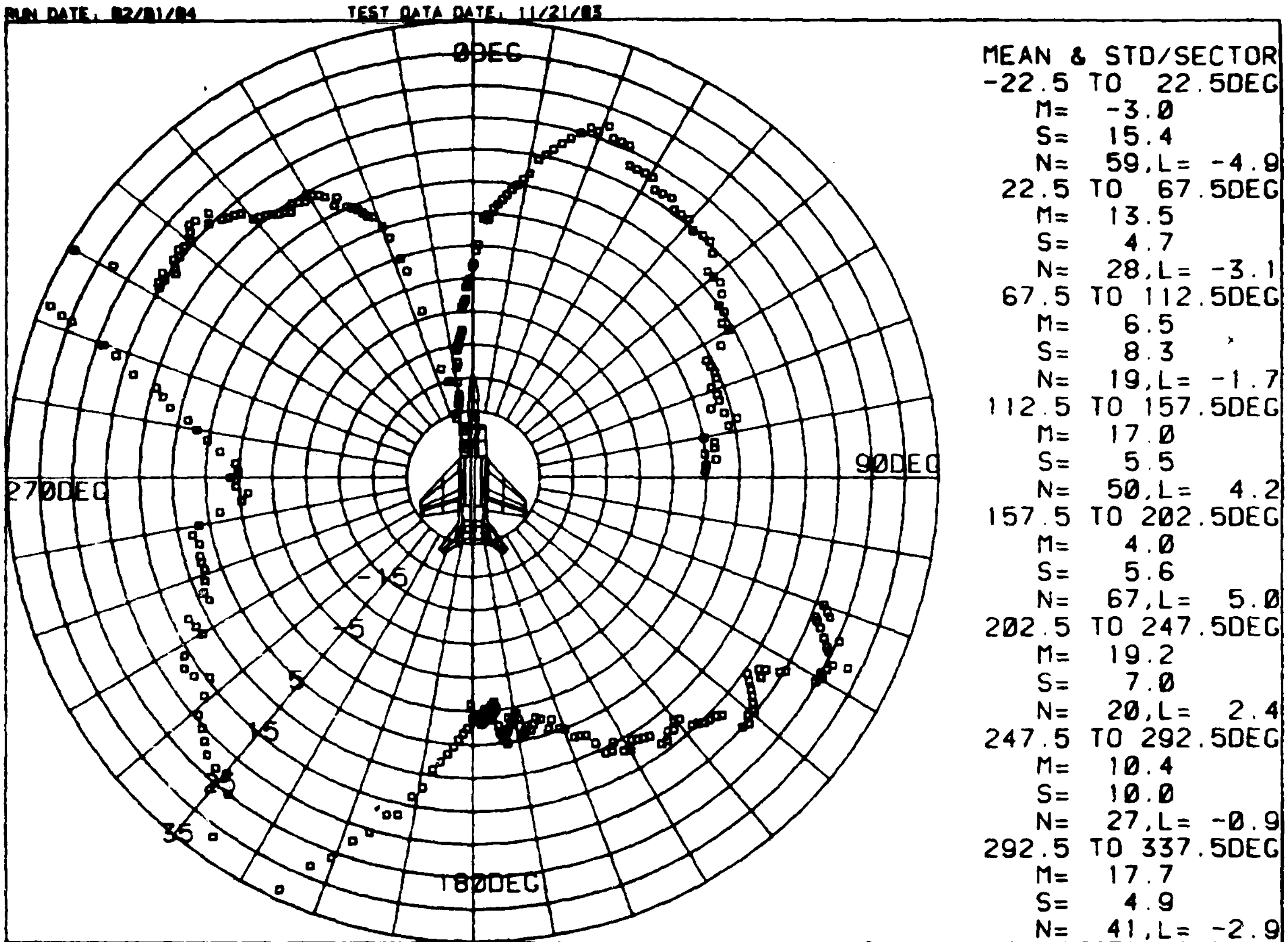
APPENDIX A

ANGLE OF ARRIVAL ACCURACY AND ANTENNA DATA



TCAS AOA ERROR VERSUS AZIMUTH, TOP ANTENNA(41815 TO 42532SECS)

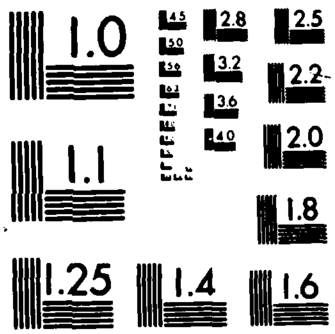

TCAS AZIMUTH IN DEGREES
TRACKER AZIMUTH IN DEGREES
TCAS AOA ERROR TOP ANTENNA (41815 TO 42532 SEC)

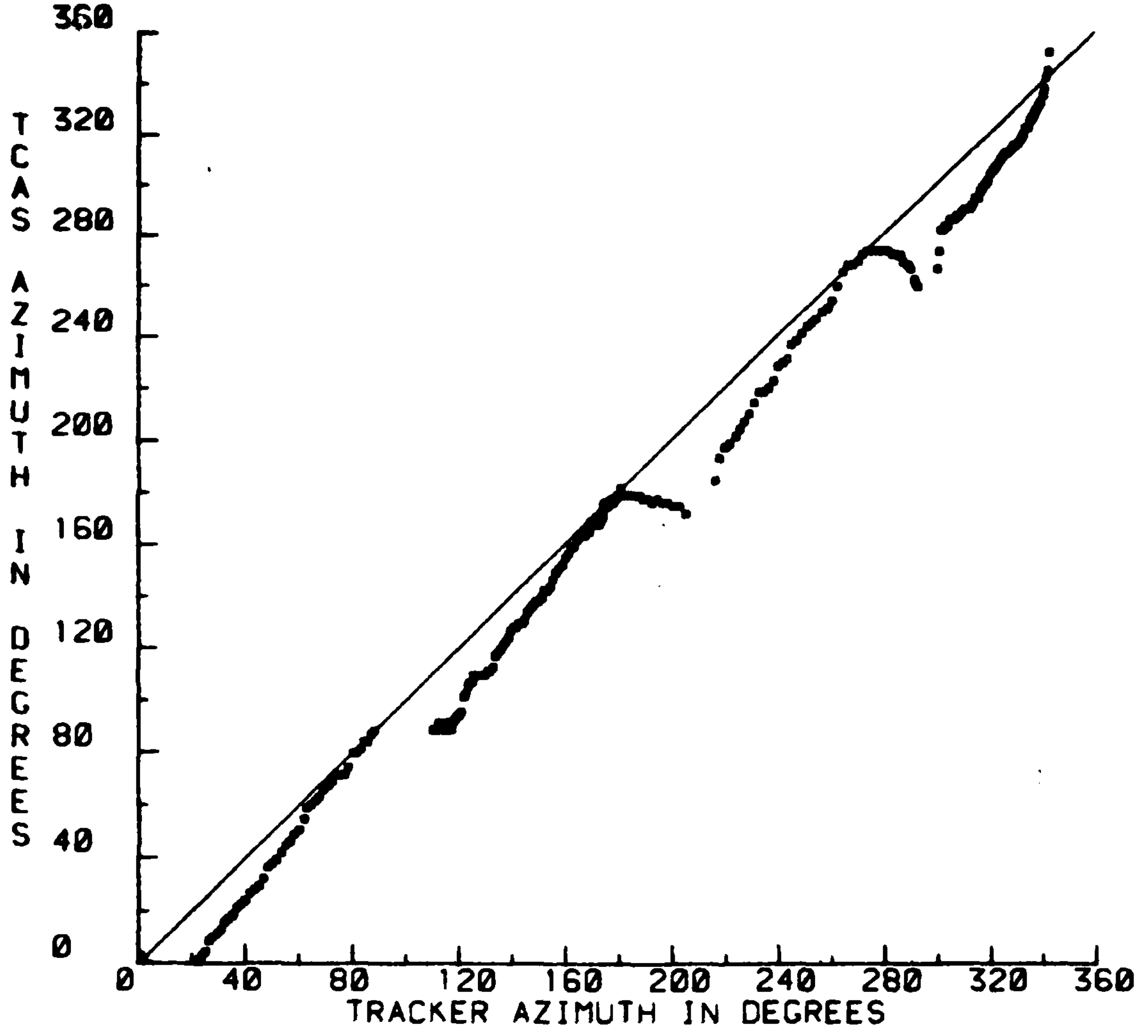


TCAS AOA ERROR VERSUS AZIMUTH, TOP ANTENNA(37608 TO 37933SECS)

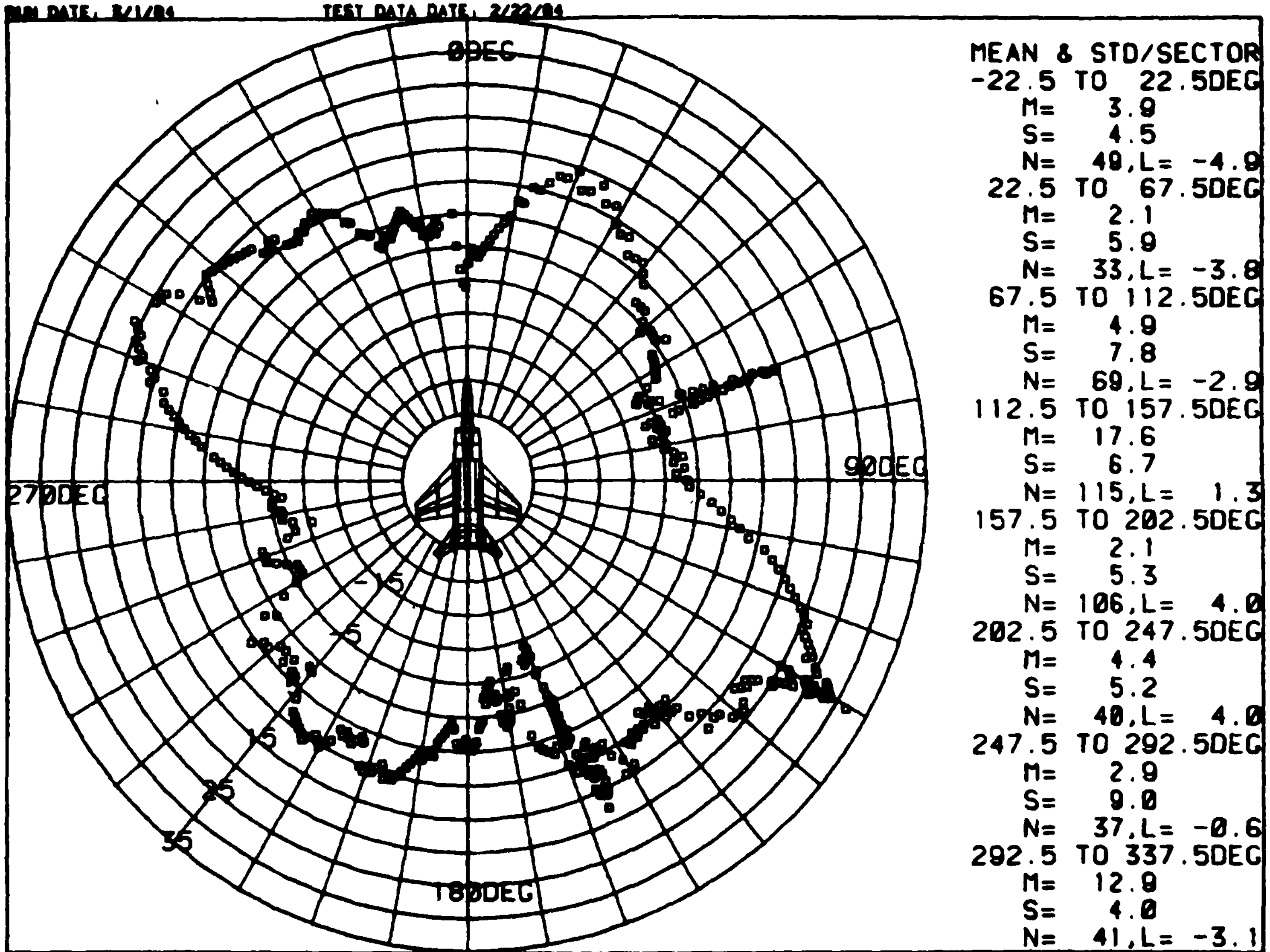
AD-A172 260 COMPREHENSIVE TEST AND EVALUATION OF THE DALMO VICTOR TCAS (TRAFFIC ALERT..(U) FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER ATLANTIC CIT.. 2/3

UNCLASSIFIED A J REHMAN FEB 86 DOT/FAA/CT-86/2 F/G 1/2 NL

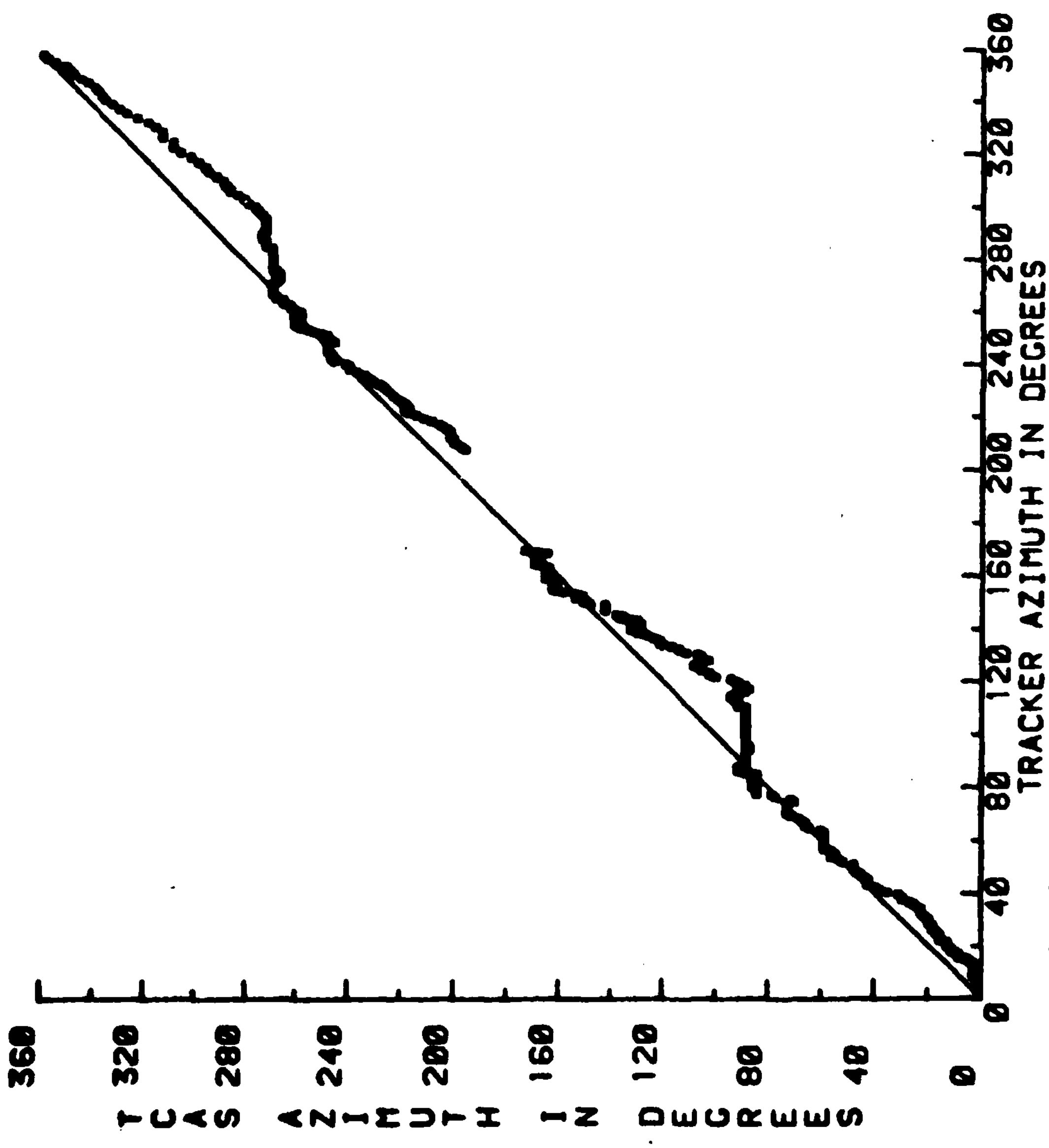

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0



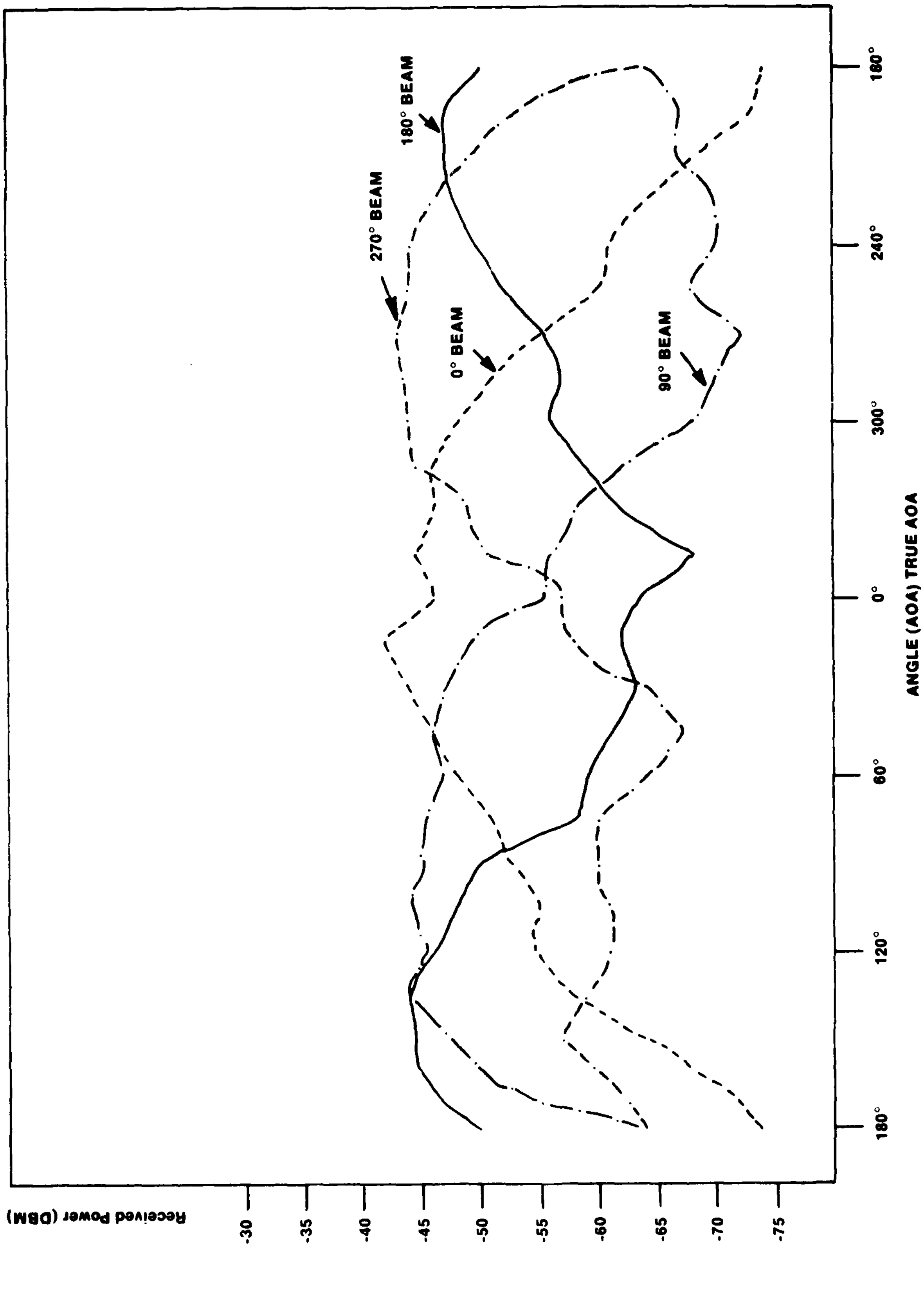
TCAS AOA ERROR TOP ANTENNA (37608 TO 37933 SEC)

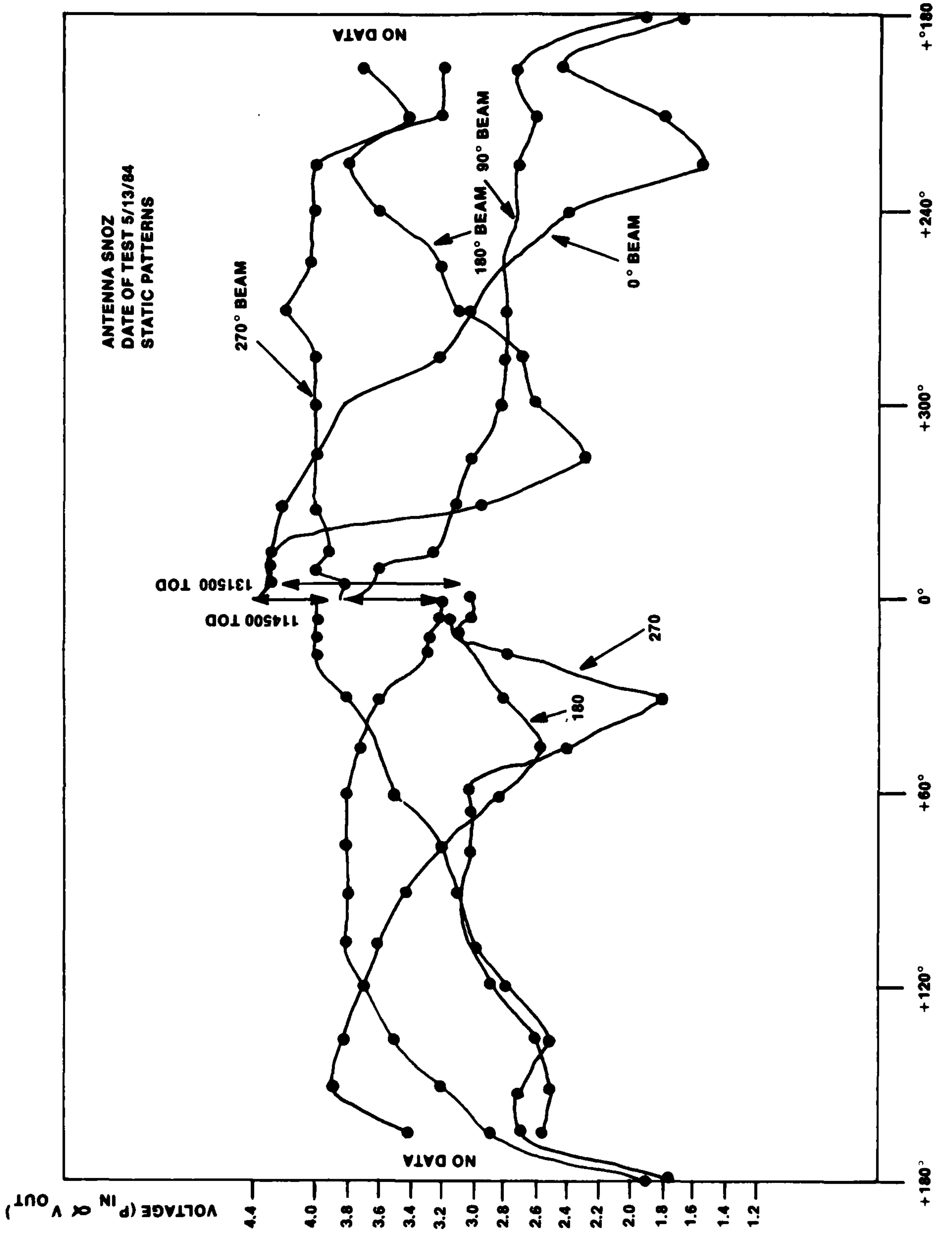


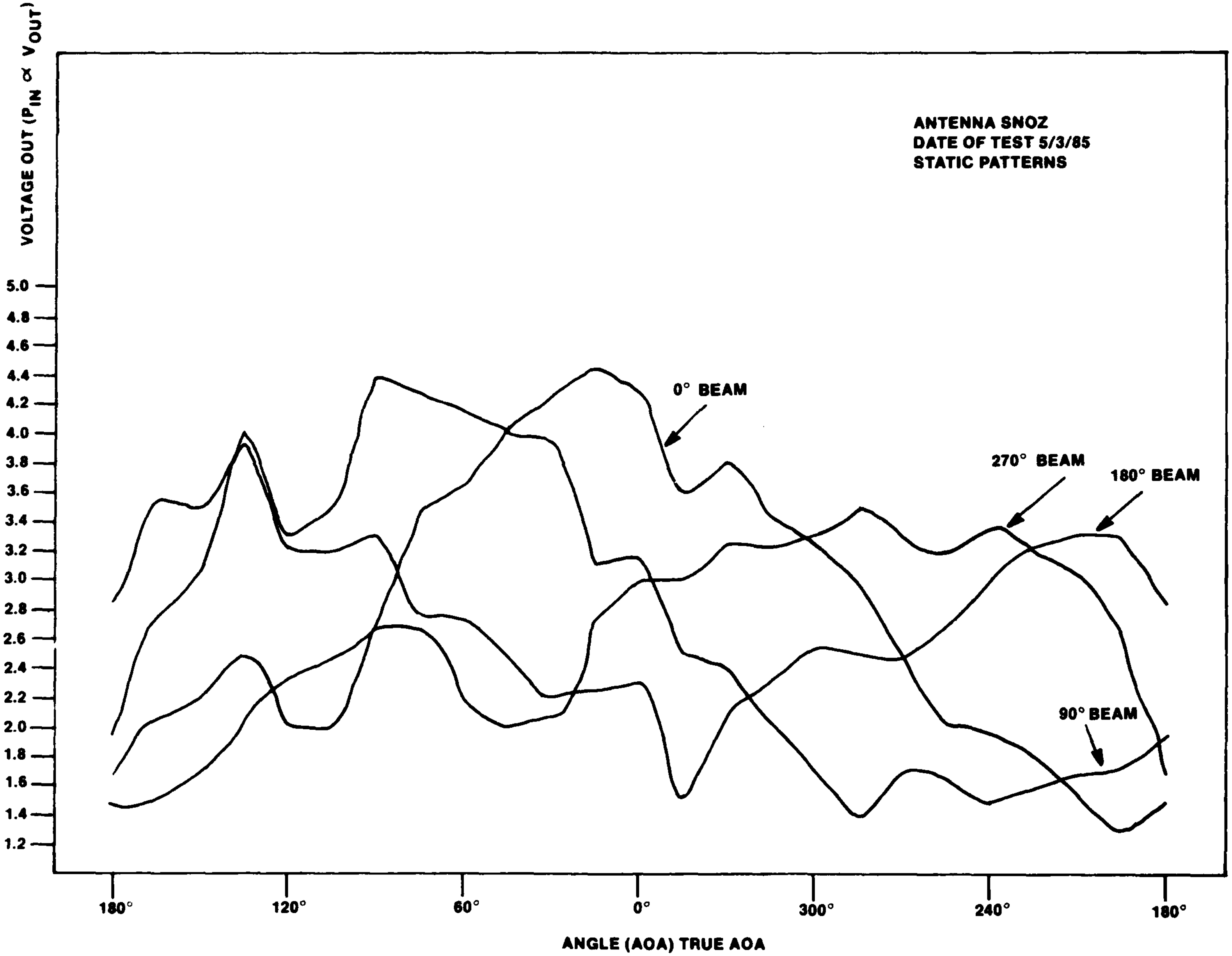
TCAS AOA ERROR VERSUS AZIMUTH, TOP ANTENNA(36545 TO 37095SECS)



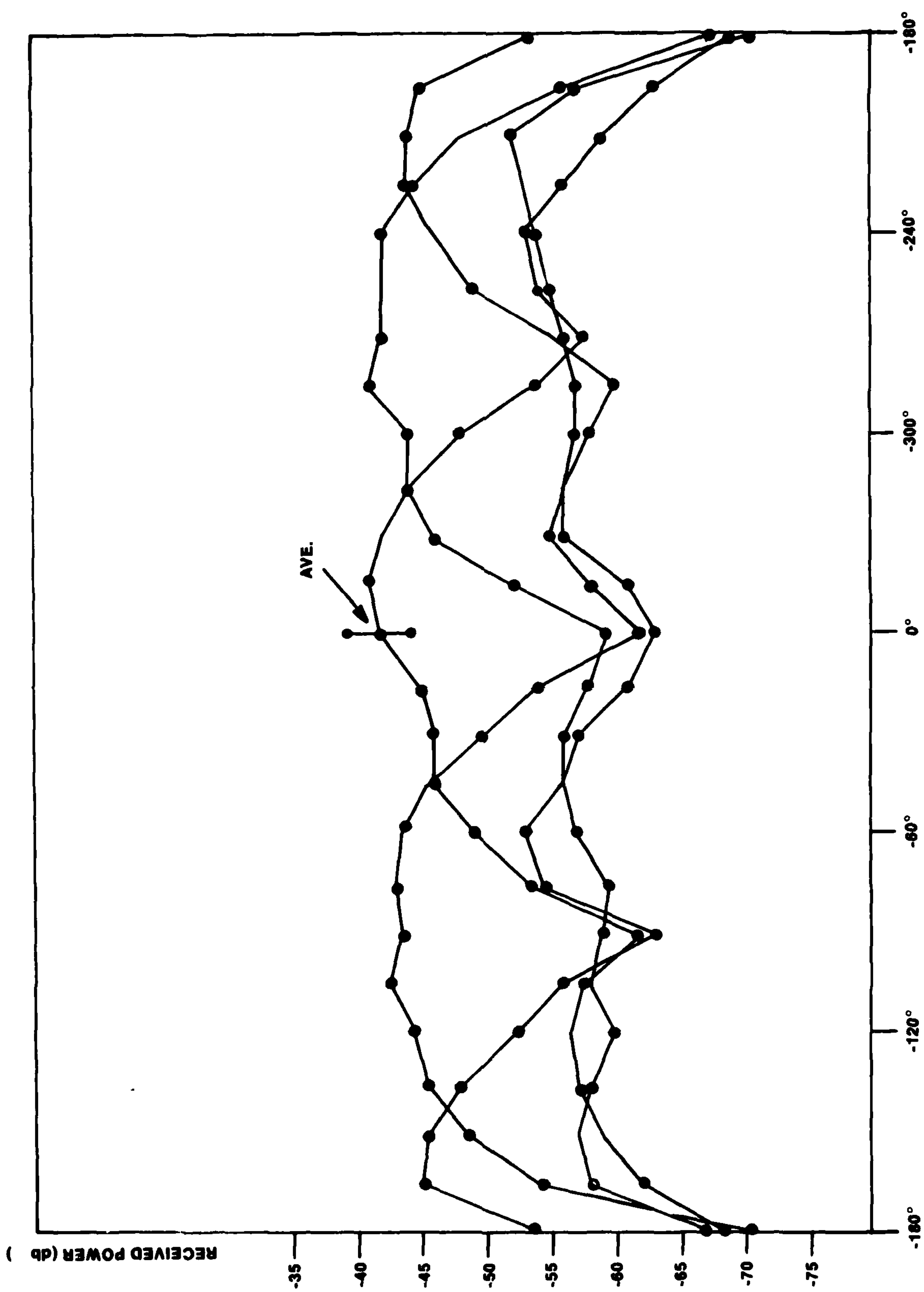
TCAS AOA ERROR TOP ANTENNA (35228 TO 35664 SEC)

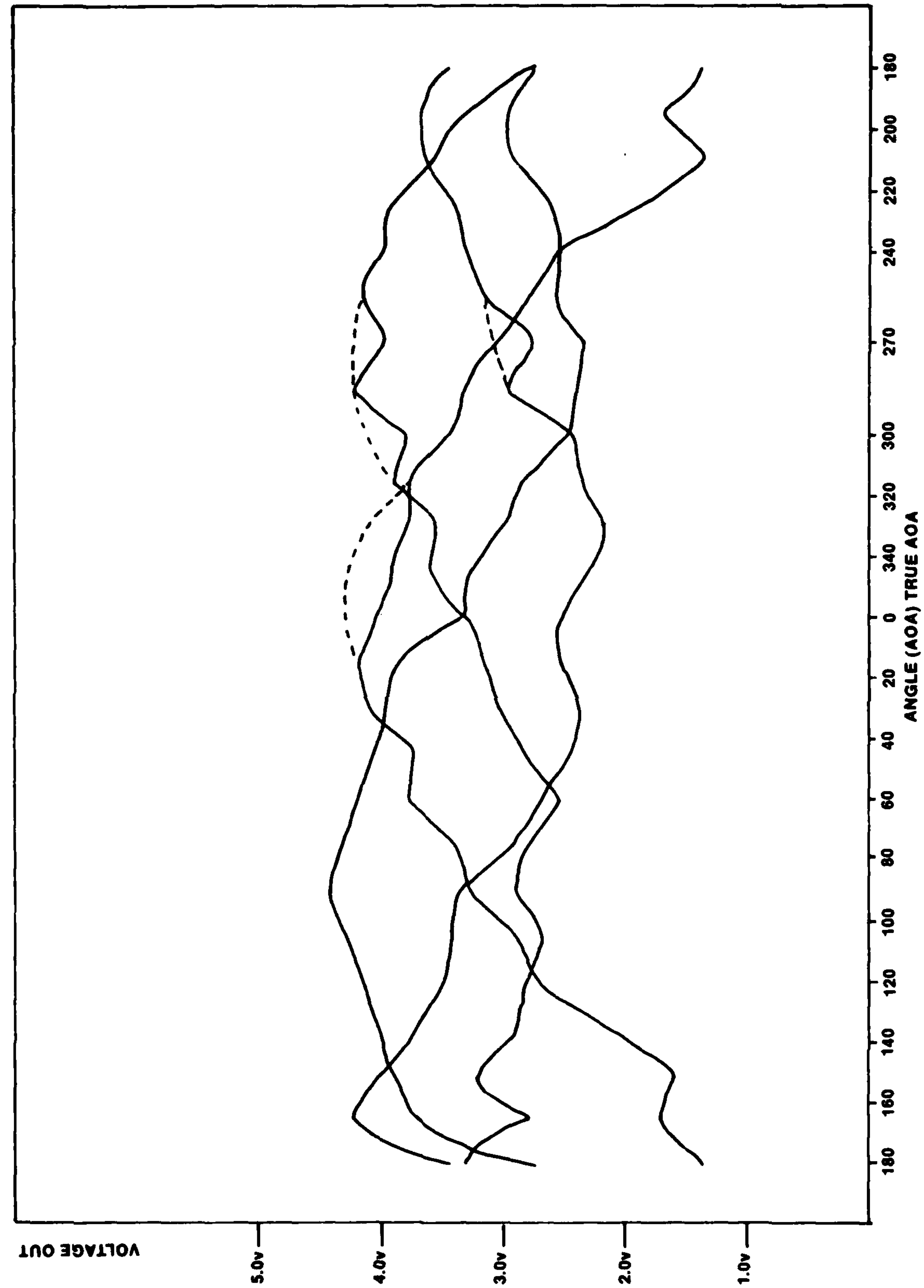

180° BEAM
270° BEAM
0° BEAM
90° BEAM
Received Power (DBM)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
180°
120°
60°
0°
300°
240°
180°
ANGLE (AOA) TRUE AOA


ANTENNA SNOZ
DATE OF TEST 5/13/84
STATIC PATTERNS
270° BEAM
180° BEAM
90° BEAM
0° BEAM
NO DATA
NO DATA
131500 TOD
114500 TOD
270
180
VOLTAGE (P IN ∝ V OUT)
4.4
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
+180°
+240°
+300°
0°
+60°
+120°
+180°

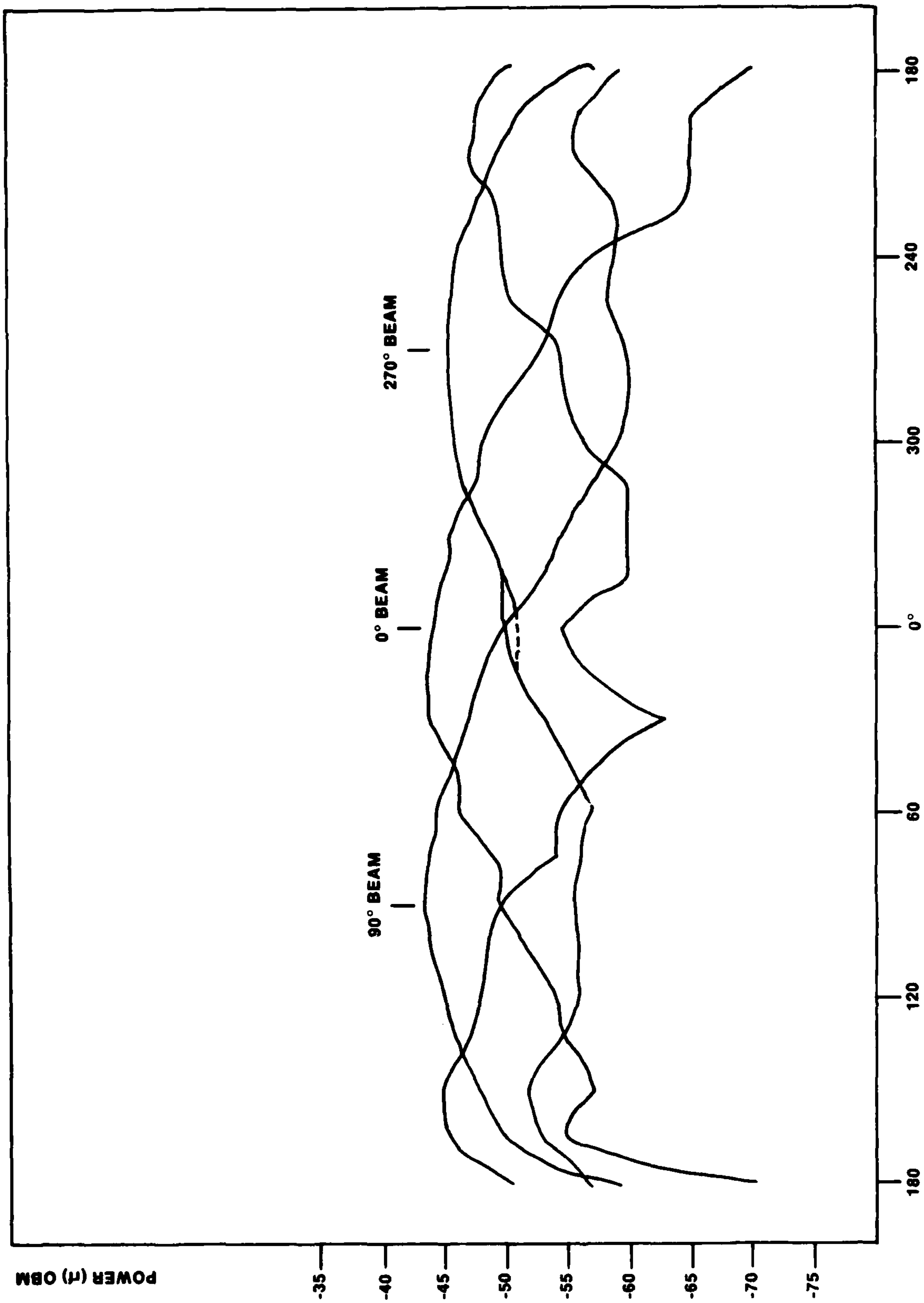


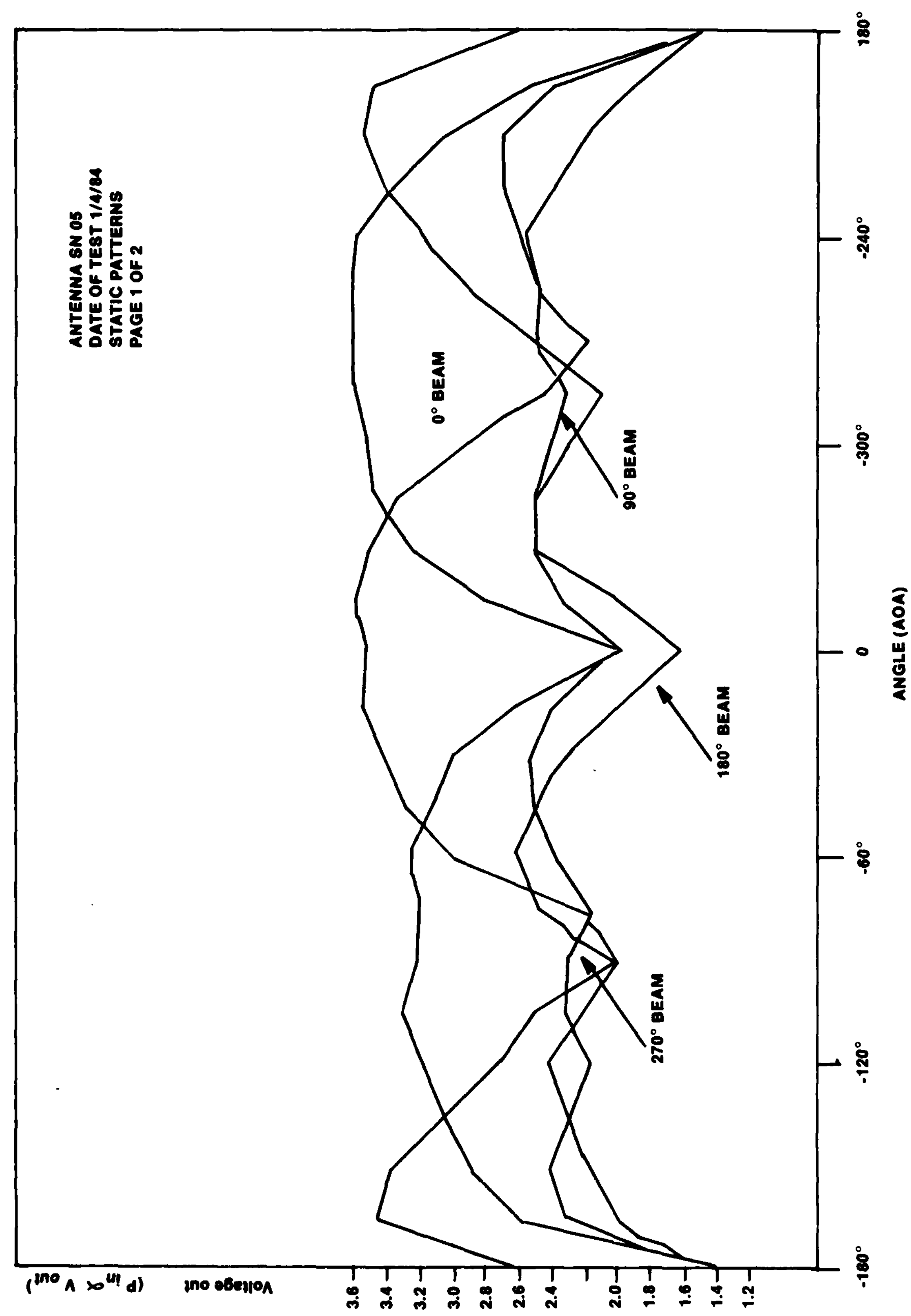
ANTENNA SNOZ
DATE OF TEST 5/3/85
STATIC PATTERNS
VOLTAGE OUT ($P_{IN} \propto V_{OUT}$)
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
0° BEAM
270° BEAM
180° BEAM
90° BEAM
180°
120°
60°
0°
300°
240°
180°
ANGLE (AOA) TRUE AOA


RECEIVED POWER (db)
-35
-40
-45
-50
-55
-60
-65
-70
-75
-180°
-240°
-300°
0°
-60°
-120°
-180°
AVE.


VOLTAGE OUT
5.0v
4.0v
3.0v
2.0v
1.0v
ANGLE (AOA) TRUE AOA
180
200
220
240
270
300
320
340
0
20
40
60
80
100
120
140
160
180

ANTENNA SN06
2/23/84




ANTENNA SN 05
DATE OF TEST 1/4/84
STATIC PATTERNS
PAGE 1 OF 2
0° BEAM
90° BEAM
180° BEAM
270° BEAM
Voltage out
(P in ∝ V out)
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.0
1.8
1.6
1.4
1.2
-180°
-120°
-60°
0
-300°
-240°
180°
ANGLE (AOA)

APPENDIX B

FLIGHT SUMMARY DATA FROM TERMINAL OPERATIONS

FLIGHT SUMMARY

MISSION 070683A.

Destination: Atlanta, GA

Flight Date: July 6, 1983

Mission Type: Approaches (six completed)

Purpose: Medium density tracking evaluation

Departure: 09:27:00

Arrival: 11:58:50

Total Flight Time: 2 hours, 31 minutes, 50 seconds

TCAS Configuration: Display generator: Airborne Intelligent Display.
Computer and RF Units - serial No. 01 Antenna-SN01
CAS Logic Load: Version 11.0

Known Deficiencies:
1. Inoperative intruder-on-ground suppression logic
2. Bearing tracker logic
3. CAS establishment criterion = 3 hits
4. Inoperative multipath elimination, aircraft installation N-78.

SUMMARY DATA.

Total Advisories: 39; 30 Mode C includes 25 TA's and 5 RA's; 9 Non-Mode C TA's.

Advisories Eliminated by Piedmont Suppression Logic = 28.

Valid Advisories = 11; Mode C = 5, includes 5 TA's; Non-Mode C = 6 TA's.

Total Advisories Display Time: 365 seconds

Total Time Bearing was Invalid: 26 seconds (14%)

Problems Encountered in Flight:

Type: Engineering, TASCORE not assigned correctly. As functioning, TA's can have higher display priority than RA's.

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Mode C	48s	40s	33	No	1000 ft	0.40	1200	Range (TRTRU)	No	Approach	5000	5	(1)
2.	TA-Mode C	6s	9s	33	No	-	-	-	-	No	Approach	4800	5	(1)
3.	TA-Mode C	5s	-	2	No	-	-	-	-	Yes-1	Final	1450	4	
4.	TA-Mode C	5s	-	5	No	-	-	-	-	Yes-1	Final	1431	4	
5.	TA-Mode C	5s	-	8	Yes	-	-	-	-	Yes-1	Final	1393	4	
6.	TA-Mode C	5s	-	7	No	-	-	-	-	Yes-1	Final	1218	2	
7.	TA-Mode C	10s	-	2	Yes	-	-	-	-	Yes-1	Final	1300	2	
8.	TA-Mode C	7s	-	38	Yes	-	-	-	-	Yes-1	Final	1168	2	
9.	TA-Non-Mode C	7s	-	3	Yes (2s) Concurrent Tracks	-	-	-	Range (TRTRU)	Yes-2	Final	950	2	(2)
10.	TA-Non-Mode C	10s	-	10	No	-	-	-	Range (TRTRU)	No	Final	950	2	(3)
11.	TA-Mode C	16s	-	26	No	-	-	-	-	Yes-1	Depart	1000	2	
12.	TA-Mode C	5s	-	26	No	-	-	-	-	Yes-1	Depart	1175	2	
13.	TA-ModeC	2s	-	22	Yes (1s)	-	-	-	-	Yes-1	Depart	1337	2	(4)
14.	TA-Mode C	4s	26s	26	No	-	-	-	-	Yes-1	Depart	1316	2	(5)
15.	TA-Non-Mode C	5s	18s	5	No	-	-	-	-	Yes-1	Depart	1437	4	(6)
16.	TA-Mode C	2s	-	15	Yes (2s)	-	-	-	-	Yes-1	Depart	1718	4	
17.	TA-Mode C	5s	16s	32	Yes (1s)	1000 ft	1.62	1000	Range (TRTRU)	No	Depart	2100	4	(6)
18.	TA-Mode C	20s	39s	30	No	350 ft	2.16	-700	Range (TRTRU)	No	Pattern	3900	5	(7)
19.	TA-Non-Mode C	10s	24s	6	No	-	1.19	-	Range (TRTRU)	No	Pattern	4768	5	
20.	TA-Mode C	5s	38s	44	Yes (5s)	775 ft	6.5	769	-	Yes-3	Pattern	4925	5	(8)

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
21. RA-LD 2000	6s	-	7	Yes (2s)	-	-	-	-	Yes-1	Final	1581	4	(9)
22. RA-ND	8s	-	27	Yes (3s)	-	-	-	-	Yes-1	Final	1543	4	(10)
23. TA-Non-Mode C	6s	-	18	No	-	-	-	-	Yes-2	Final	1093	2	
				Concurrent Tracks									
24. TA-Non-Mode C	10s	1s	28	No	-	0.34	-	-	No	Final	1106	2	(11)
25. TA-Mode C	5s	-	32	No	-	-	-	-	Yes-1	Depart	1362	2	(12)
26. RA-LD2000	9s	-	32	No	-	-	-	-	Yes-1	Depart	1450	4	(13)
27. TA-Mode C	7s	-	32	No	-	-	-	-	Yes-1	Depart	1650	4	(13)
28. TA-Mode C	6s	-	38	Yes (6s)	-	-	-	-	Yes-3	Pattern	3493	2	(13)
29. TA-Mode C	2s	-	13	Yes (2s)	-	-	-	-	Yes-1	Final	1068	2	(14)
30. TA-Non-Mode C	24s	17s	22	No	-	0.18	-	-	No	Depart	1168	2	
31. TA-Mode C	2s	-	30	Yes (1s)	-	-	-	-	Yes-1	Depart	1312	2	(15)
32. RA-Climb	4s	-	30	No	-	-	-	-	Yes-1	Depart	1412	4	(16)
33. TA-Mode C	9s	-	8	No	-	-	-	-	Yes-1	Depart	1212	4	(16)
34. RA-Climb	5s	-	8	Yes (1s)	-	-	-	-	Yes-1	Depart	1462	4	(17)
35. TA-Mode C	1s	-	43	No	-	-	-	-	Yes-1	Depart	1625	4	(17)
36. TA-Mode C	39s	40s	42	No	-	1.7	-	Range (TRTRU)	No	Pattern	4862	5	(18)
37. TA-Non-Mode C	8s	25s	14	No	-	0.94	-	-	No	Approach	3900	5	
38. TA-Mode C	2s	-	42	No	350	-	-	-	Yes-1	Final	1381	2	(19)
39. TA-Non-Mode C	30s	25s	18	No	-	0.45	-	-	No	Depart	3968	5	

070683A - Page 2 of 3

Notes:

(1) Same aircraft, TA oscillation
(2) Multipath track
(3) Real aircraft
(4) Short TA due to data loss
(5) Short TA due to track drop
(6) Short TA due to track drop
(7) Parallel departure
(8) Track drop stopped advisory
(9) No pilot response
(10) Multipath track
(11) Real aircraft
(12) TA transmitioned to RA, RA transition back to TA false track impact display
(13) Real aircraft
(14) TA transmition to RA
(15) TA transmition to RA
(16) Real aircraft
(17) Track dropped
(18) Real aircraft
(19) Yes-1 implies that intruder-on-ground suppression, as implemented in Peidmont TCAS, would inhibit this advisory
Yes-2 implies that multipath rejection, as implemented in Piedmont TCAS, would inhibit this advisory
Yes-3 implies that false track advisory rejection (4 hit/5 hit criterion), as implemented in Piedmont TCAS, would inhibit this advisory.

PROTOTYPE TEST FLIGHT 7/6/83-A

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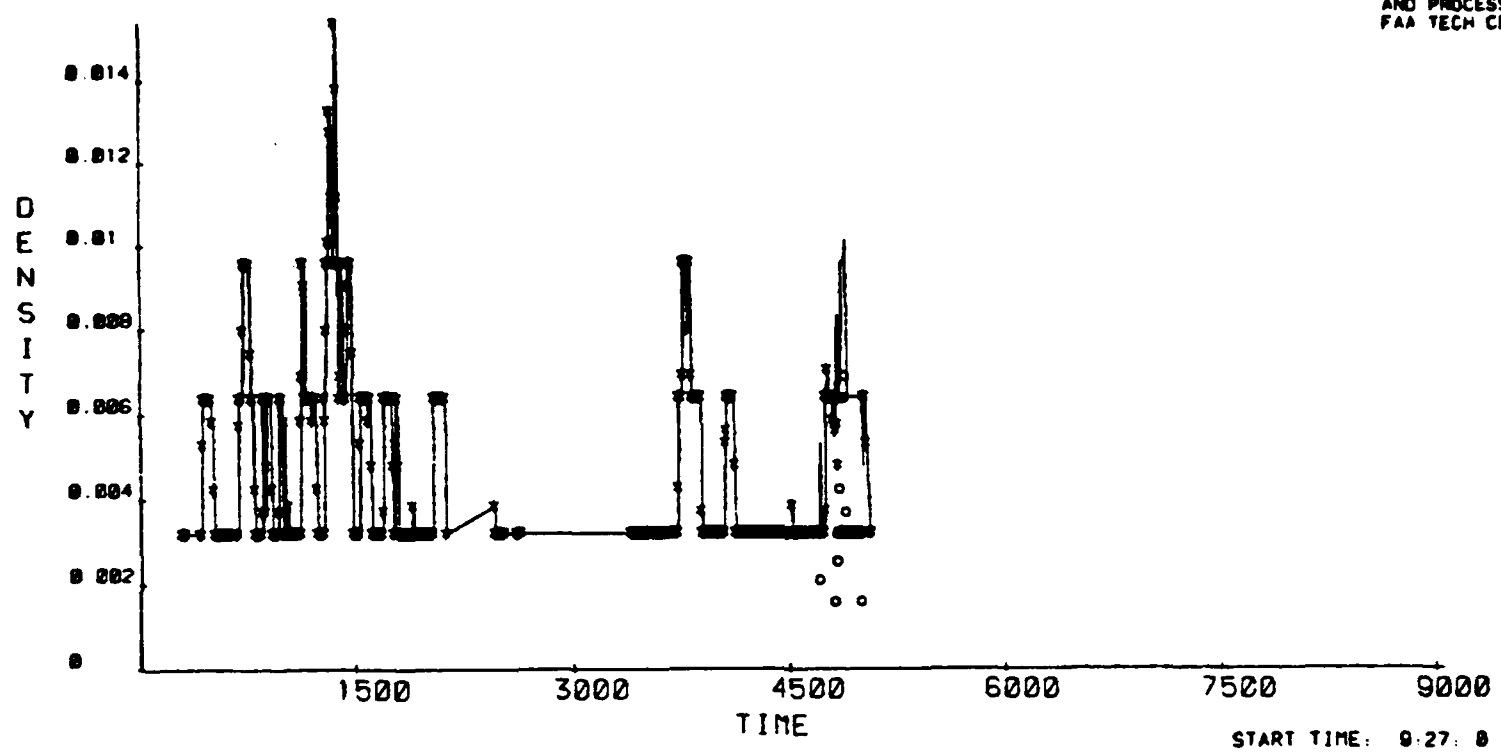

START TIME: 9:27: 0
STOP TIME: 11:58: 0

PRESENT COAST STATE	FUTURE COAST STATE 0	1	2	3	4	5	6
0	0.95	0.06	0	0	0	0	0
1	0.69	0	0.32	0	0	0	0
2	0.45	0	0	0.55	0	0	0
3	0.33	0	0	0	0.67	0	0
4	0.21	0	0	0	0	0.70	0
5	0.09	0	0	0	0	0	0.91
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME: 9:31:30
STOP TIME: 10:51:30

PRESENT COAST STATE	FUTURE COAST STATE 0	1	2	3	4	5	6
0	0.82	0.18	0	0	0	0	0
1	0.68	0	0.32	0	0	0	0
2	0.5	0	0	0.5	0	0	0
3	0.8	0	0	0	0.2	0	0
4	0	0	0	0	0	1.00	0
5	0	0	0	0	0	0	1.00
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C	***
NON MODE C	ooo
TOTAL	——

UPDATE RATES

MODE C	91%
NON MODE C	78%

PROCESSING DATE: APRIL 5,1985

NOTES:

FLIGHT SUMMARY

MISSION 070683B.

Destination: Norfolk, VA

Flight Date: July 6, 1983

Mission Type: Approaches (three completed)

Purpose: Non-Mode C tracking evaluation

Departure: Dobbins AFB 13:52:40

Arrival: FAA Technial Center 16:02:14.

Total Flight Time: 2 hours, 9 minutes, 34 seconds

TCAS Configuration: Same as mission 070683A

SUMMARY DATA.

Total Advisories: 13; Non-Mode C = 10, includes 3 RA's and 7 TA's; Non-Mode C = 3

Advisories Eliminated by Piedmont Suppression Logic: 4; Mode C = 4, includes 3 TA's and 1 RA, Non Mode C = 0.

Valid Advisories = 9*; Mode C = 6, Non-Mode C = 3

(*Note: Of these advisories, 4 Mode C advisories, 2 TA's and 2 RA's, were generated against one aircraft on final approach to ACY.)

Total Advisory Display Time: 107 seconds

Total Time Bearing was Invalid: 2 seconds (1.9%)

Problems Encountered in Flight:

1. Type: Operational, in slow closing encounters, rate jitter caused TA code oscillation resulting in several sequential advisories against the same intruder.

2. Engineering, see mission 070683A.

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Non-Mode C	25s	Divergent Target	6	No	-	0.2	-	DMOD (TAUR)	No	Final	500	2	
2.	TA-Mode C	2s	-	29	Yes (2 sec)	-	-	-	Range (TRTRU)	Yes-1	Depart	581	4	
3.	TA-Non-Mode C	6s	Divergent Target	6	No	-	0.3	-	DMOD (TAUR)	No	Depart	531	4	
4.	TA-Mode C	1s	35s	21	No	-387 ft	1	see line 5	Range (TRTRU)	No	Pattern	1850	4	(1)
5.	TA-Mode C	9s	33s	21	No	-87 ft	1.87	106	Range (TRTRU)	No	Pattern	1968	4	(1)
6.	TA-Mode C	20s	35s	18	No	531 ft	0.27	730	Range (TRTRU)	No	Pattern	1868	4	
7.	TA-Mode C	17s	-	34	No	same aircraft	see line 6			Yes-1	Final	250	2	(2)
8.	RA	6s	-	34	No	same aircraft	see line 6			Yes-1	Depart	650	4	(3)

The following advisories were issued during the approach to ACY airport:

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
9.	TA-Mode C	7s	-	31	No	same aircraft	see line 13		.	Yes-1	Depart	762	4	(4)
10.	TA-Mode C	19s	35s	31	No	-568	same aircraft		Range (TRTRU)	No	Approach	1900	4	(5)
11.	RA	7s	20s	31	No	-606	same aircraft		Range (TRTRU)	No	Approach	1818	4	(6)
12.	TA-Mode C	7s	16s	31	No	-1056	same aircraft		Range (TAUR)	No	Approach	1625	4	(7)
13.	RA	4s	16s	31	No	-606	0.93	-743	Range (TAUR)	No	Final	1600	4	(8)

Notes:

(1) Same aircraft; TA oscillation
(2) TA; same aircraft
(3) Aircraft-RA
(4) TA after the RA
(5) TA same aircraft
(6) Aircraft-RA
(7) TA after the RA
(8) RA

PROTOTYPE TEST FLIGHT 7/6/83-B

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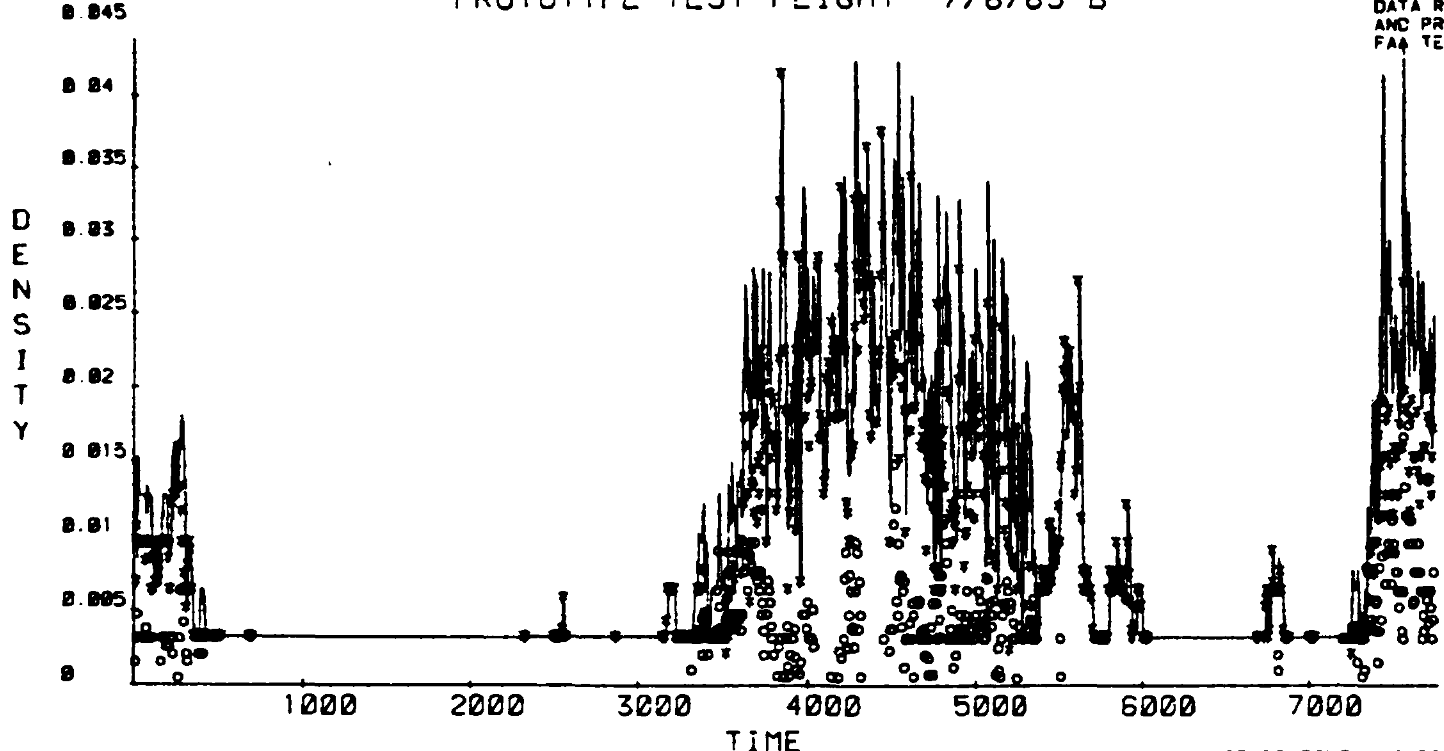

START TIME: 13:52:40
STOP TIME: 16: 2.14

MODE C MATRIX

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.88	0.13	0	0	0	0	0
1	0.67	0	0.33	0	0	0	0
2	0.53	0	0	0.47	0	0	0
3	0.41	0	0	0	0.59	0	0
4	0.26	0	0	0	0	0.74	0
5	0.17	0	0	0	0	0	0.83
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.87	0.13	0	0	0	0	0
1	0.56	0	0.44	0	0	0	0
2	0.39	0	0	0.61	0	0	0
3	0.32	0	0	0	0.68	0	0
4	0.19	0	0	0	0	0.81	0
5	0.06	0	0	0	0	0	0.94
6	1.00	0	0	0	0	0	0

START TIME: 13:52:52
STOP TIME: 16: 2: 6

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 82%
NON MODE C 78%

PROCESSING DATE: APRIL 5,1985

NOTES:

FLIGHT SUMMARY

MISSION 070783A.

Destination: JFK Airport, NY

Flight Date: July 7, 1983

Mission Type: Typical Operation, JFK-ACY

Purpose: Medium density tracking evaluation

Departure: Technial Center (ACY) 09:23:00

Arrival: ACY 09:51:10

Total Flight Time: 0 hours, 28 minutes, 10 seconds

TCAS Configuration: Same as mission 070683A

SUMMARY DATA.

Total Advisories: 1; Mode C TA

Valid Advisories: 1

Problems Encountered in Flight:

Type: Engineering, noticed several D-1 failures; indicates data bus failure.

No summary data provided for this event due to recorder data loss.

PROTOTYPE TEST FLIGHT 7-7-83A

DATA RECORDED
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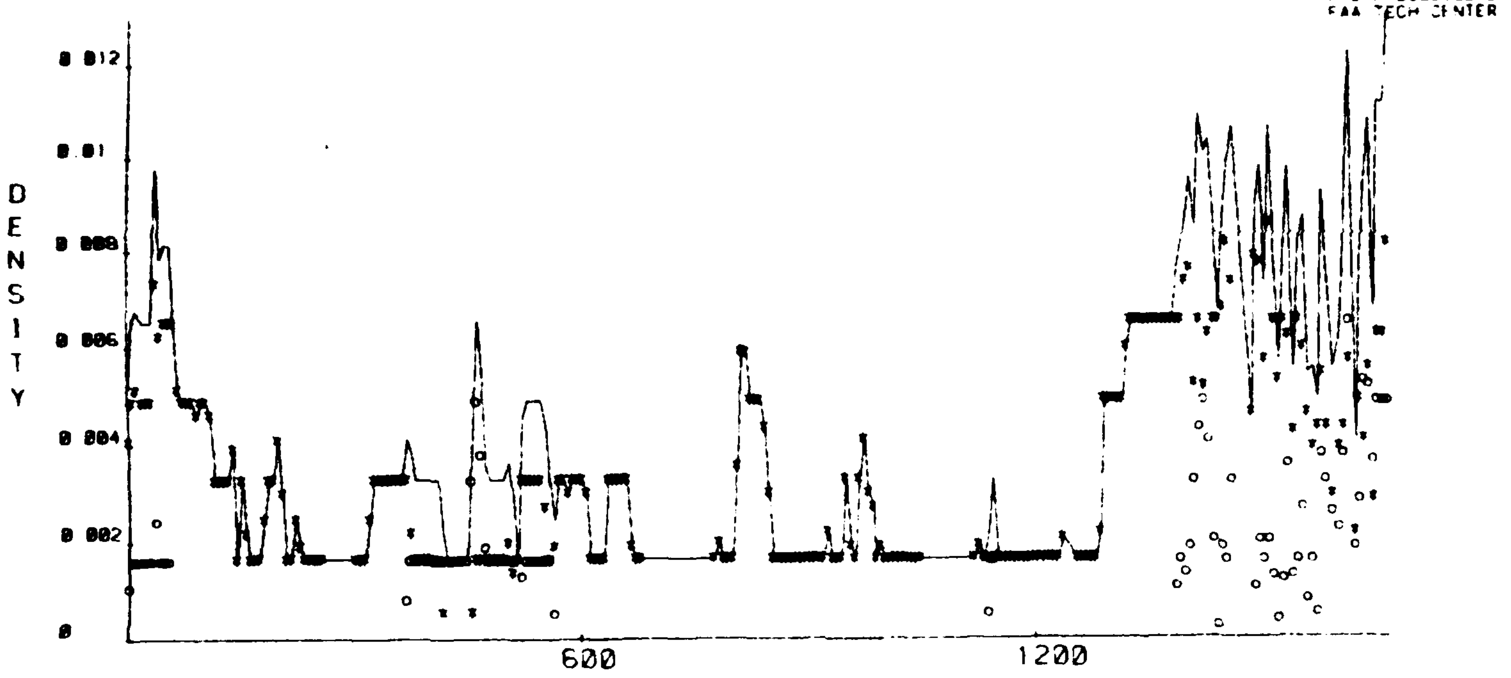

START TIME 9 23 33
STOP TIME 9 51 26

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.9	0.1	0	0	0	0	0
1	0.73	0	0.28	0	0	0	0
2	0.35	0	0	0.65	0	0	0
3	0.26	0	0	0	0.74	0	0
4	0.18	0	0	0	0	0.82	0
5	0.07	0	0	0	0	0	0.93
6	1.00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.88	0.12	0	0	0	0	0
1	0.64	0	0.35	0	0	0	0
2	0.22	0	0	0.74	0	0	0
3	0.4	0	0	0	0.6	0	0
4	0	0	0	0	0	1.00	0
5	0.33	0	0	0	0	0	0.67
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME. 9.23.33
STOP TIME. 9.51.26

LEGEND

MODE C ***
NON MODE C ooo
TOTAL —

UPDATE RATES

MODE C 85%
NON MODE C 80%

PROCESSING DATE, OCT 15,1984

NOTES:

FLIGHT SUMMARY

MISSION 070783B.

Destination: JFK Airport, NY

Flight Date: July 7, 1983

Mission Type: Typical operation, JFK-ACY

Purpose: Medium density tracking evaluation

Departure: JFK 12:51:00

Arrival: Technical Center (ACY) 14:09:08

Total Flight Time: 1 hour, 18 minutes, 8 seconds

TCAS Configuration: Same as mission 070683A

SUMMARY DATA.

Total Advisories: 3; Mode C = 2, includes 0 RA's and 2 TA's; Non-Mode C = 1

Advisories Eliminated by Piedmont Suppression Logic: 2; Mode C = 2

Valid Advisories = 1; Mode C = 0, Non-Mode C = 1

Total Advisory Display Time: 13 seconds

Total Time Bearing was Invalid: 1 second (7.7%)

Problems Encountered in Flight:

Type: Engineering, D-1 failure caused by 429 BUS problem.

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Non-Mode C	2s	245s	8	No	-	1.52	-	TRTRU	No	En route	4800	5	
2.	TA-Mode C	6s	-	40	No	-	-	-	DMOD	Yes-1	Final	-200	2	
3.	TA-Mode C	6s	-	40	No	-	-	-	DMOD	Yes-1	Final	-200	2	

PROTOTYPE TEST FLIGHT 7-7-83B

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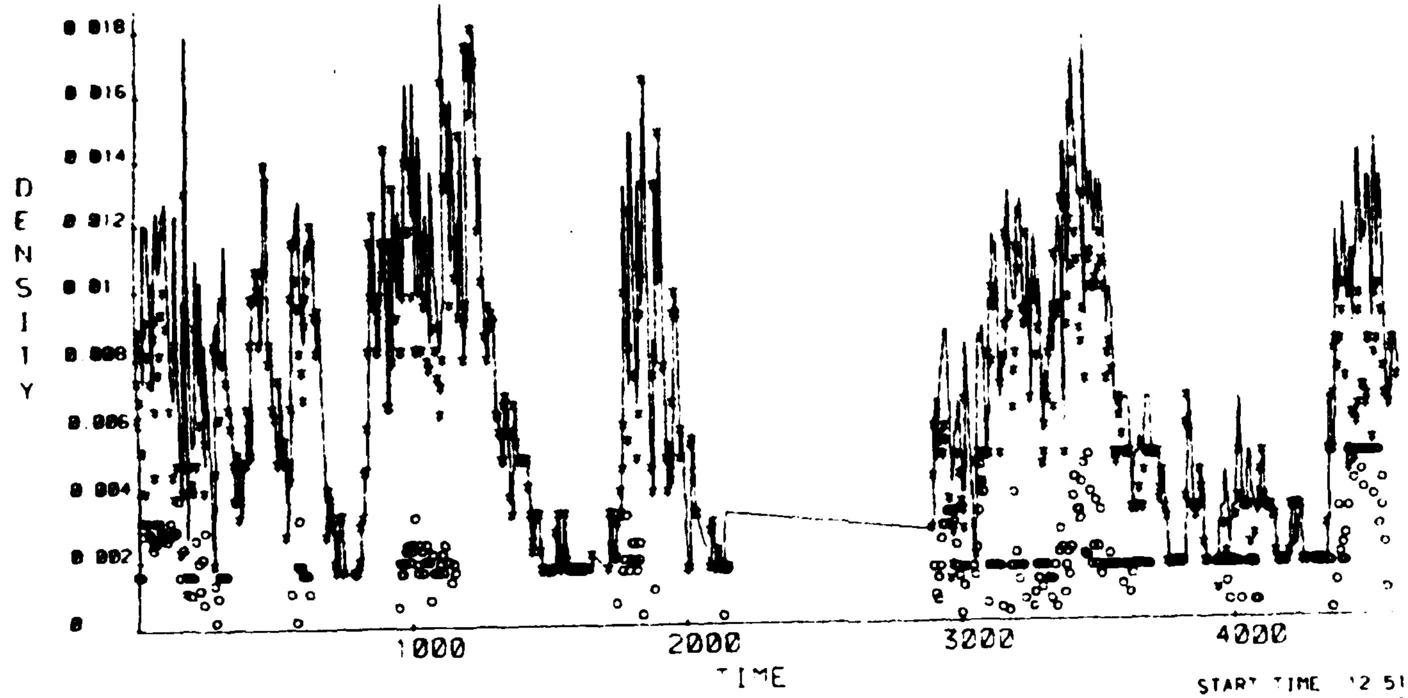

START TIME 12 51 54
STOP TIME 14 8.53

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.85	0.15	0	0	0	0	0
1	0.65	0	0.35	0	0	0	0
2	0.48	0	0	0.52	0	0	0
3	0.35	0	0	0	0.65	0	0
4	0.22	0	0	0	0	0.78	0
5	0.00	0	0	0	0	0	0.01
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME 12 51 54
STOP TIME 14 8 53

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.86	0.14	0	0	0	0	0
1	0.69	0	0.31	0	0	0	0
2	0.42	0	0	0.58	0	0	0
3	0.32	0	0	0	0.68	0	0
4	0.18	0	0	0	0	0.82	0
5	0.3	0	0	0	0	0	0.7
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL —

UPDATE RATES

MODE C 79%
NON MODE C 80%

PROCESSING DATE, OCT 15, 1984

NOTES:

FLIGHT SUMMARY

MISSION 071983.

Destination: Philadelphia, PA

Flight Date: July 19, 1983

Mission Type: Approaches (three completed)

Purpose: Approach mission; subject pilot operational evaluation

Departure: Technical Center (ACY) 13:37:54

Arrival: ACY at 14:27:24

Total Flight Time: 0 hours, 49 minutes, 30 seconds

TCAS Configuration: Same as mission 070683A

SUMMARY DATA.

Total Advisories: 5; Mode C = 4, includes 3 TA's and 1 RA; Non-Mode C = 1

Advisories Eliminated by Piedmont Suppression Logic: 1; Mode C TA

Valid Advisories = 4; Mode C = 3, Non-Mode C = 1

Total Advisory Display Time: 109 seconds

Total Time Bearing was Invalid: 0 seconds (0%)

Problems Encountered in Flight: None

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Non-Mode C	25s	20s	24	No	-	0.33	-	TAURTA	No	Departure ACY	1237	4	
2.	TA-Mode C	15s	35s	42	No	331 ft	2.02	456	TRTRU	No	Departure ACY	1893	4	
3.	TA-Mode C	35s	-	26	No	-	-	-	TRTRU	Yes-1	Final	250	2	(1)
4.	TA-Mode C	22s	37s	15	No	-	see line 5		TRTRU	No	Pattern	2150	4	(2)
5.	RA-Climb	17s	18s	15	No	593 ft	0.71	-500	TRTRU	No	Approach	1950	4	(2)

Notes:

(1) Intruder on ground
(2) Same aircraft

071983

PROTOTYPE TEST FLIGHT 7-19-83B

DATA RECORDED
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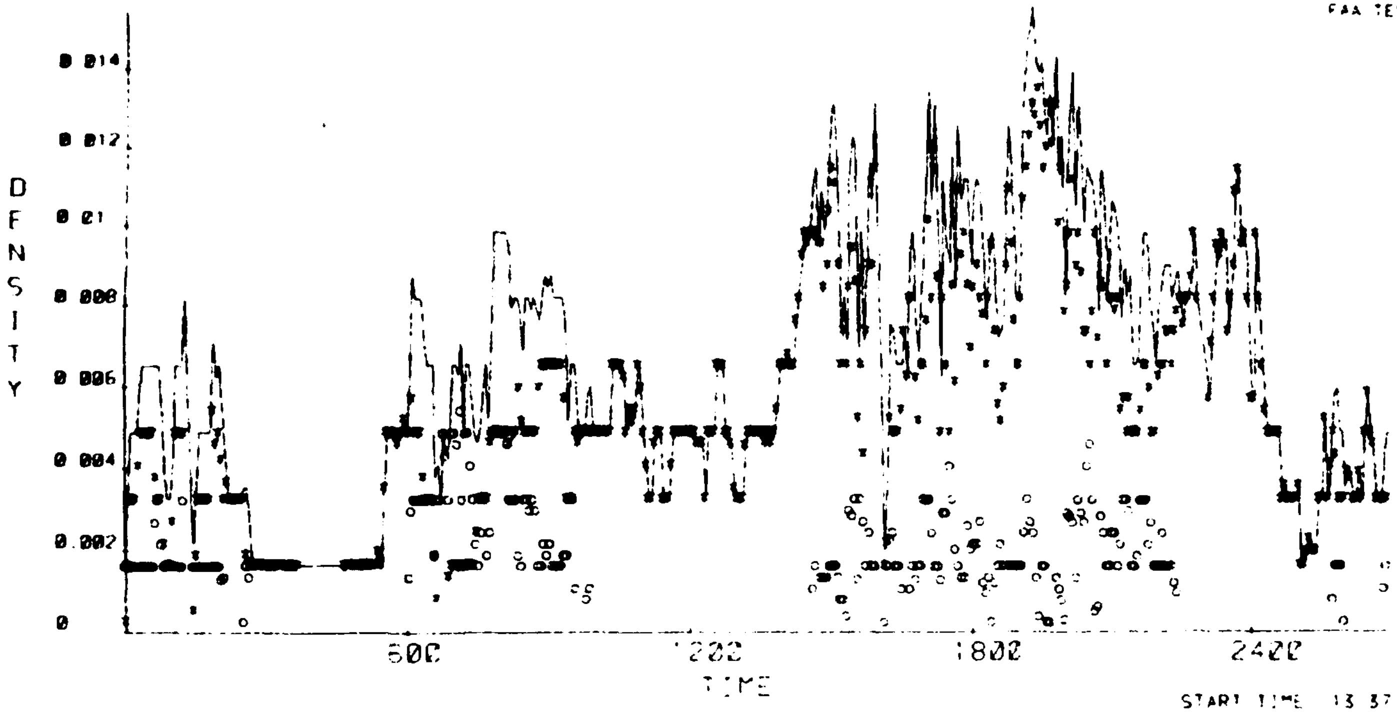

START TIME 13 37 58
STOP TIME 14 22 52

MODE C MATRIX (FUTURE COAST STATE across, PRESENT COAST STATE down)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.91	0.09	0	0	0	0	0
1	0.72	0	0.28	0	0	0	0
2	0.56	0	0	0.44	0	0	0
3	0.43	0	0	0	0.57	0	0
4	0.28	0	0	0	0	0.72	0
5	0.22	0	0	0	0	0	0.78
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX (FUTURE COAST STATE across, PRESENT COAST STATE down)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.86	0.14	0	0	0	0	0
1	0.59	0	0.41	0	0	0	0
2	0.44	0	0	0.56	0	0	0
3	0.18	0	0	0	0.82	0	0
4	0.27	0	0	0	0	0.73	0
5	0.22	0	0	0	0	0	0.78
6	1.00	0	0	0	0	0	0

START TIME 13.37.58
STOP TIME 14.22 52

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ---

UPDATE RATES

MODE C 87%
NON MODE C 78%

PROCESSING DATE: OCT 15,1984

NOTES.

FLIGHT SUMMARY

MISSION 081183.

Destination: Washington, DC (DCA)

Flight Date: August 11, 1983

Mission Type: Approaches (five completed at DCA, three at ACY)

Purpose: Medium density tracking evaluation

Departure: Technical Center (ACY) 10:05:29

Arrival: ACY 12:29:56

Total Flight Time: 2 hours, 24 minutes, 27 seconds

TCAS Configuration: Same as mission 070683

SUMMARY DATA.

Total Advisories: 41: Mode C = 34, includes 28 TA's and 6 RA's; Non-Mode C = 7

Advisories Eliminated by Piedmont Suppression Logic = 36; Mode C = 33, includes 27 TA's and 6 RA's; Non-Mode C = 3

Valid Advisories = 5; Mode C = 1, Non-Mode C = 4

Total Advisory Display Time: 373 seconds

Total Time Bearing was Invalid: 58 seconds (15.5%)

Problems encountered in Flight = one type engineering: RA sequence with no accompanying audio.

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Mode C	11s	-	33	No	0	-	-	TRTRU	Yes-1	Final	160	2	(1) (1)
2.	RA-ND Mode C	8s	-	33	No	0	-	-	DMOD	Yes-1	Depart	660	4	(1)
3.	TA-Mode C	4s	-	33	No	1125 ft	-	-	TAURTA	Yes-1	Depart	950	4	
4.	TA-Mode C	2s	-	27	Yes (2s)	468 ft	-	-	TRTRU	Yes-1	Depart	660	4	
5.	TA-Mode C	3s	-	4	Yes (1s)	0	-	-	DMOD	Yes-1	Final	300	2	
6.	TA-Non-Mode C	21s	17s	38	No	-	0.2	-	TAURTA	No	Final	300	2	(2)
7.	TA-Non-Mode C	1s	-	33	No	-	-	-	TAURTA	Yes-2,3	Pattern	2968	4	(3)
8.	TA-Non-Mode C	1s	-	33	Yes (1s)	-	-	-	TAURTA	Yes-2,3	Pattern	3093	4	(4)
9.	TA-Non-Mode C	6s	-	0	Yes (1s)	-	-	-	TAURTA	Yes-2,3	Pattern	2968	4	(5)
10.	TA-Non-Mode C	6s	-	9	Yes (5s)	-1106 ft	-	-	TRTRU	Yes-2	Pattern	2350	4	(6)
11.	TA-Non-Mode C	28s	18s	6	Yes (5s)	-	0.5	-	TAURTA	No	Approach	850	4	(7)
12.	TA-Mode C	8s	-	40	No	225 ft	-	-	TRTRU	Yes-1	Final	650	4	(8)
13.	TA-Non-Mode C	10s	-	40	No	368 ft	-	-	TRTRU	Yes-1	Final	350	2	(8)
14.	TA-Non-Mode C	24s	26s	28	No	375 ft	0.72	768	TRTRU	No	Depart	1850	4	(9)
15.	TA-Non-Mode C	40s	18s	26	No	-	0.2	-	TAURTA	No	Pattern	3075	3	(10)
16.	RA-ND	7s	-	10	Yes (7s)	300 ft	-	-	TRTRU	Yes-1	Approach	950	4	
17.	TA-Mode-C	2s	-	7	Yes (1s)	75 ft	-	-	TRTRU	Yes-1	Final	650	4	
18.	RA-ND	6s	-	7	Yes (2s)	375 ft	-	-	TRTRU	Yes-1	Final	650	4	
19.	TA-Mode-C	4s	-	22	No	362 ft	-	-	TRTRU	Yes-1	Final	600	4	
20.	TA-Mode-C	5s	-	19	Yes (5s)	0	-	-	TAURTA	Yes-2	Final	350	2	

081183 - Page 1 of 3

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Range (nmi)	Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
21. TA-Mode C	15s	-	22	No	406 ft	-	-	TRTRU	Yes-1	Depart	418	2	
22. TA-Mode C	3s	-	16	Yes (2s)	0 ft	-	-	DMOD	Yes-1	Final	418	2	
23. TA-Mode C	1s	-	21	Yes (1s)	0 ft	-	-	DMOD	Yes-1	Final	160	2	
24. TA-Mode C	8s	-	39	No	0 ft	-	-	TAURTA	Yes-1	Go-Around	200	2	
25. TA-Mode C	8s	-	26	No	0 ft	-	-	TAURTA	Yes-1	Depart	450	2	
26. TA-Mode C	9s	-	33	Yes (4s)	800 ft	-	-	TAURTA	Yes-1	Depart	700	4	
27. TA-Mode C	4s	-	40	Yes (2s)	860 ft	-	-	TRTRU	Yes-1	Approach	662	4	
28. RA-LD 2000	6s	-	40	No	606 ft	-	-	TRTRU	Yes-1	Approach	606	4	(11)
29. TA-Mode C	3s	-	37	Yes (1s)	0 ft	-	-	TAURTA	Yes-1	Final	168	2	
30. TA-Mode C	18s	-	44	No	387 ft	-	-	TRTRU	Yes-1	Go-Around	200	2	
31. TA-Non-Mode C	5s	-	44	No	737 ft	-	-	TRTRU	Yes-1	Depart	700	4	(12)
32. RA-NC D	10s	-	19	Yes (3s)	743 ft	-	-	TRTRU	Yes-1	Depart	850	4	(13)
33. TA-Mode C	8s	-	44	No	800 ft	-	-	TRTRU	Yes-1	Depart	960	4	
34. TA-Mode C	7s	-	16	Yes (3s)	862 ft	-	-	DMOD	Yes-1	Depart	1100	4	
35. TA-Mode C	2s	-	18	Yes (2s)	0 ft	-	-	TAURTA	Yes-1	Depart	5800	5	
36. TA-Non-Mode C	10s	25s	40	Yes (9s)	-	1.05	-	TAURTA	No	Pattern	5800	5	
37. TA-Mode C	20s	-	18	No	0 ft	-	-	TAURTA	Yes-1	Final	460	2	(14)
38. TA-Mode C	4s	-	18	No	0 ft	-	-	TRTRU	Yes-1	Depart	600	4	(15)
39. TA-Mode C	2s	-	18	No	-106 ft	-	-	TRTRU	Yes-1	Final	350	2	(16)

081183 - page 2 of 3

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
40. TA-Mode C	27s	-	18	No	-106	-	-	TRTRU	Yes-1	Final	350	2	
41. TA-Mode C	6s	-	3	Yes (1s)	0	-	-	DMOD	Yes-1	Final	80	2	

Notes:

(1) Same aircraft, aircraft is on ground
(2) Real threat
(3) Multipath
(4) Multipath
(5) False track
(6) False track
(7) Real Threat
(8) TA oscillation caused by performance level switch
(9) Real threat
(10) Real threat
(11) Missing RA audio
(12) Incorrect advisory sense
(13) Incorrect advisory sense
(14) TA oscillation

081183 - Page 3 of 3

PROTOTYPE TEST FLIGHT 8-11-83

DATA RECORDED
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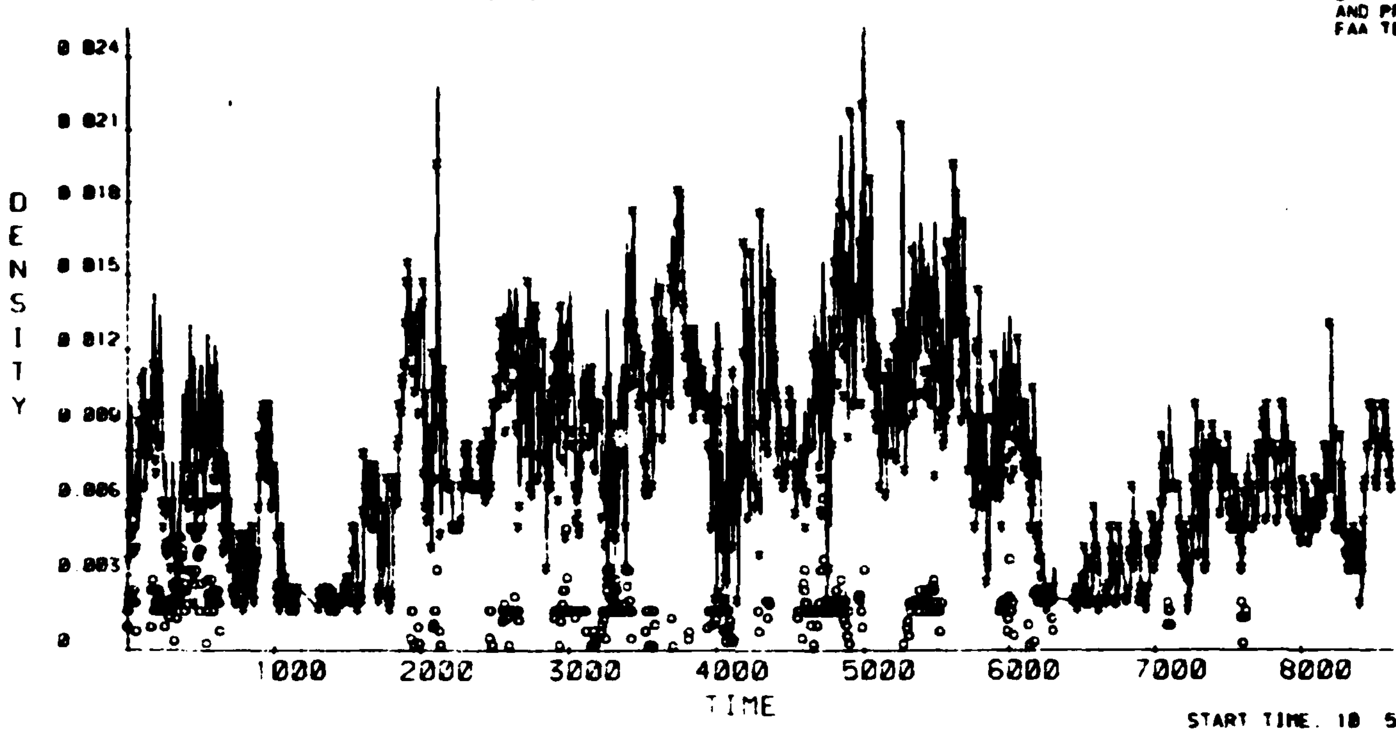

START TIME. 10 5 30
STOP TIME. 12 20.46

FUTURE COAST STATE (rows: PRESENT COAST STATE)

	0	1	2	3	4	5	6
0	0.9	0.1	0	0	0	0	0
1	0.72	0	0.28	0	0	0	0
2	0.5	0	0	0.5	0	0	0
3	0.33	0	0	0	0.67	0	0
4	0.28	0	0	0	0	0.72	0
5	0.21	0	0	0	0	0	0.8
6	1.00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE (rows: PRESENT COAST STATE)

	0	1	2	3	4	5	6
0	0.84	0.16	0	0	0	0	0
1	0.61	0	0.39	0	0	0	0
2	0.33	0	0	0.67	0	0	0
3	0.21	0	0	0	0.79	0	0
4	0.08	0	0	0	0	0.93	0
5	0.22	0	0	0	0	0	0.76
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME. 10. 5.30
STOP TIME. 12.20.46

LEGEND

MODE C ***
NON MODE C ooo
TOTAL —

UPDATE RATES

MODE C 86%
NON MODE C 74%

PROCESSING DATE. OCT 15.1984

NOTES:

FLIGHT SUMMARY

MISSION 100483A/MISSION 100483B.

Destination: MIT Lincoln Lab, Beford, MA

Flight Date: October 4, 1983

Mission Type: Surveillance data gathering

Purpose: Evaluate non-Mode C tracking

Departure: Technical Center (ACY) 10:07:00 (100483A)
Bedford 12:56:20 (100483B)

Arrival: Bedford 11:53:50 (100483A)
ACY 14:15:20 (100483B)

Total Flight Time: 3 hours, 6 minutes, 40 seconds

TCAS Configuration: Same as mission 101183A except using special surveillance data recording. No CAS data recorded.

SUMMARY DATA.

See density plot and transition matricies for surveillance performance.

PROTOTYPE TEST FLIGHT 10-4-83A

DATA RECORDED
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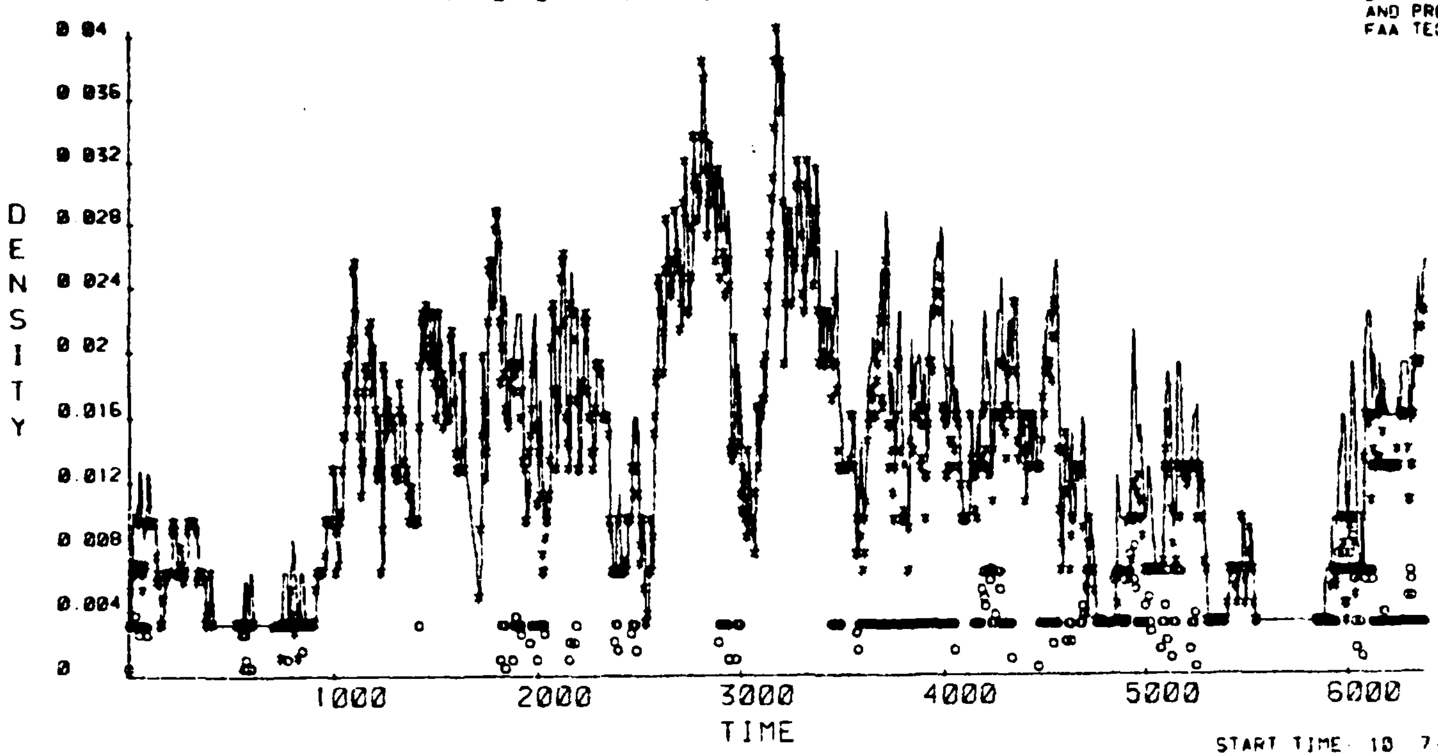


START TIME 10 7 6
STOP TIME 11 53 40

MODE C MATRIX (PRESENT COAST STATE / FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.84	0.16	0	0	0	0	0
1	0.64	0	0.36	0	0	0	0
2	0.46	0	0	0.55	0	0	0
3	0.31	0	0	0	0.69	0	0
4	0.26	0	0	0	0	0.74	0
5	0.14	0	0	0	0	0	0.86
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX (PRESENT COAST STATE / FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.85	0.16	0	0	0	0	0
1	0.63	0	0.38	0	0	0	0
2	0.41	0	0	0.59	0	0	0
3	0.21	0	0	0	0.79	0	0
4	0.15	0	0	0	0	0.86	0
5	0.13	0	0	0	0	0	0.87
6	1.00	0	0	0	0	0	0

START TIME, 10. 7. 6
STOP TIME, 11.53.40

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

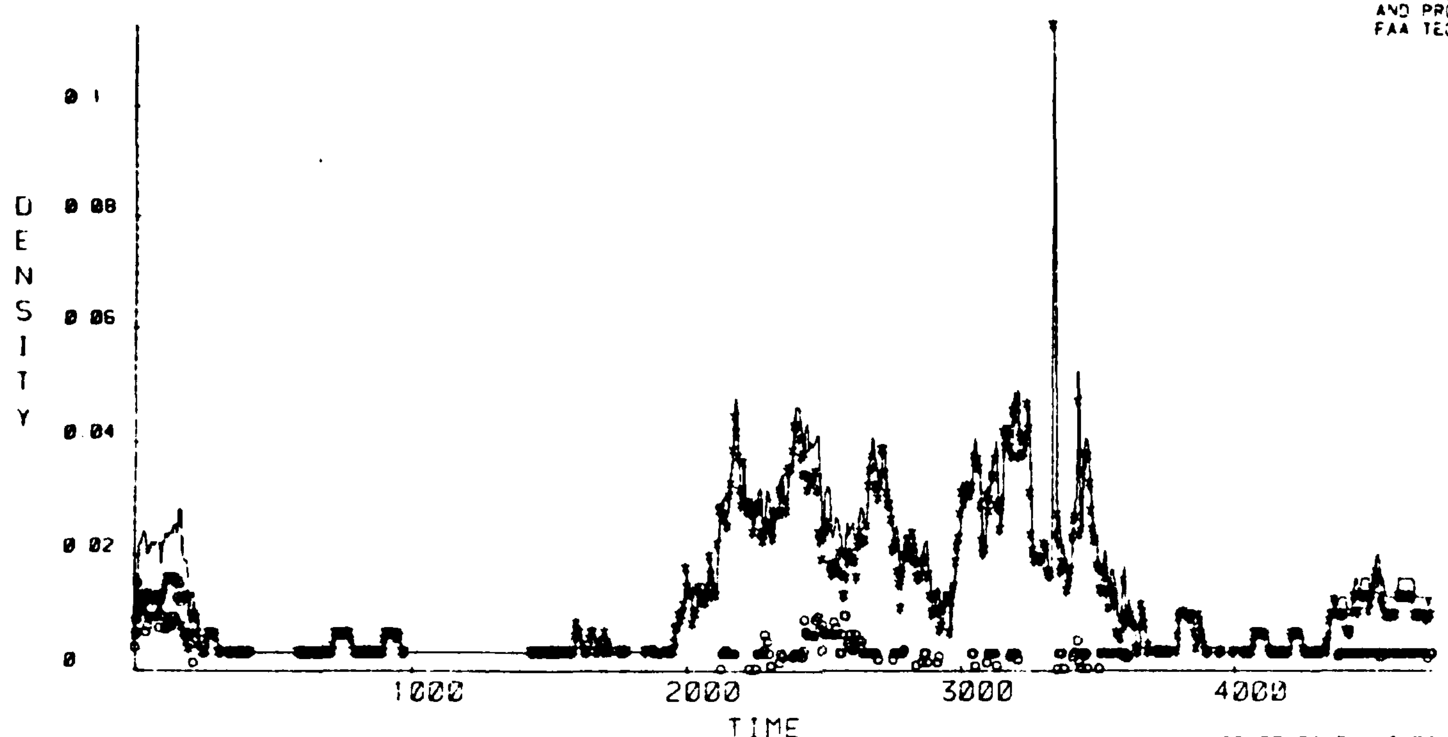
MODE C 77%
NON MODE C 76%

PROCESSING DATE OCT 30,1984

NOTES:

PROTOTYPE TEST FLIGHT 10-4-83B

DATA RECORDED AND PROCESSED BY FAA TECH CENTER



START TIME 12 56 25
STOP TIME 14 15 18

MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.82	0.18	0	0	0	0	0
1	0.59	0	0.41	0	0	0	0
2	0.4	0	0	0.6	0	0	0
3	0.29	0	0	0	0.71	0	0
4	0.2	0	0	0	0	0.8	0
5	0.18	0	0	0	0	0	0.82
6	1.00	0	0	0	0	0	0

START TIME 12 56 25
STOP TIME 14 15 18

NON MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.83	0.17	0	0	0	0	0
1	0.59	0	0.41	0	0	0	0
2	0.36	0	0	0.64	0	0	0
3	0.29	0	0	0	0.71	0	0
4	0.15	0	0	0	0	0.85	0
5	0.1	0	0	0	0	0	0.9
6	1.00	0	0	0	0	0	0

LEGEND

MODE C ***
NON MODE C ooo
TOTAL —

UPDATE RATES

MODE C 73%
NON MODE C 73%

PROCESSING DATE OCT 30, 1984

NOTES

FLIGHT SUMMARY

MISSION 101183A.

Destination: Atlanta, GA

Flight Date: October 11, 1983

Mission Type: High altitude operation

Purpose: High speed tracking evaluation; Genesco recorder evaluation

Departure: Technical Center (ACY) 10:15:00

Arrival: Hartsfield Airport, Atlanta, GA, 13:07:48. From ACY, N-40 flew direct to Jacksonville, FL, overflew JAX at FL34 and direct to Atlanta.

Total Flight Time: 2 hours, 51 minutes, 41 seconds

TCAS Configuration: Display generator: Sperry/Dalmo Victor supplied computer and RF units-serial 02; antenna SN05 CAS logic load: version 11.10 (Piedmont configuration) known deficiencies:

1. Intruder on ground threshold at 850 feet (Piedmont 1350 feet).
2. CAS coding error in low firmness logic.
3. Audio alerts sometimes missing.

Aircraft installation N-40.

SUMMARY DATA.

Total Advisories: 1; Non-Mode C (occurred on ACY departure)

Advisories Eliminated by Piedmont Suppression Logic: 0

Valid Advisories = 1

Total Advisory Display Time: 26 seconds

Total Time Bearing was Invalid: 0 seconds (0%)

	Advisory Type	Duration	Warning Time	Track ID	Bid Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA (non-Mode C)	[illegible]	[illegible]	[illegible]	[illegible]	-	0.68		TAURTA	No	Departure	1468	4	

10118

PROTOTYPE TEST FLIGHT 10-11-83

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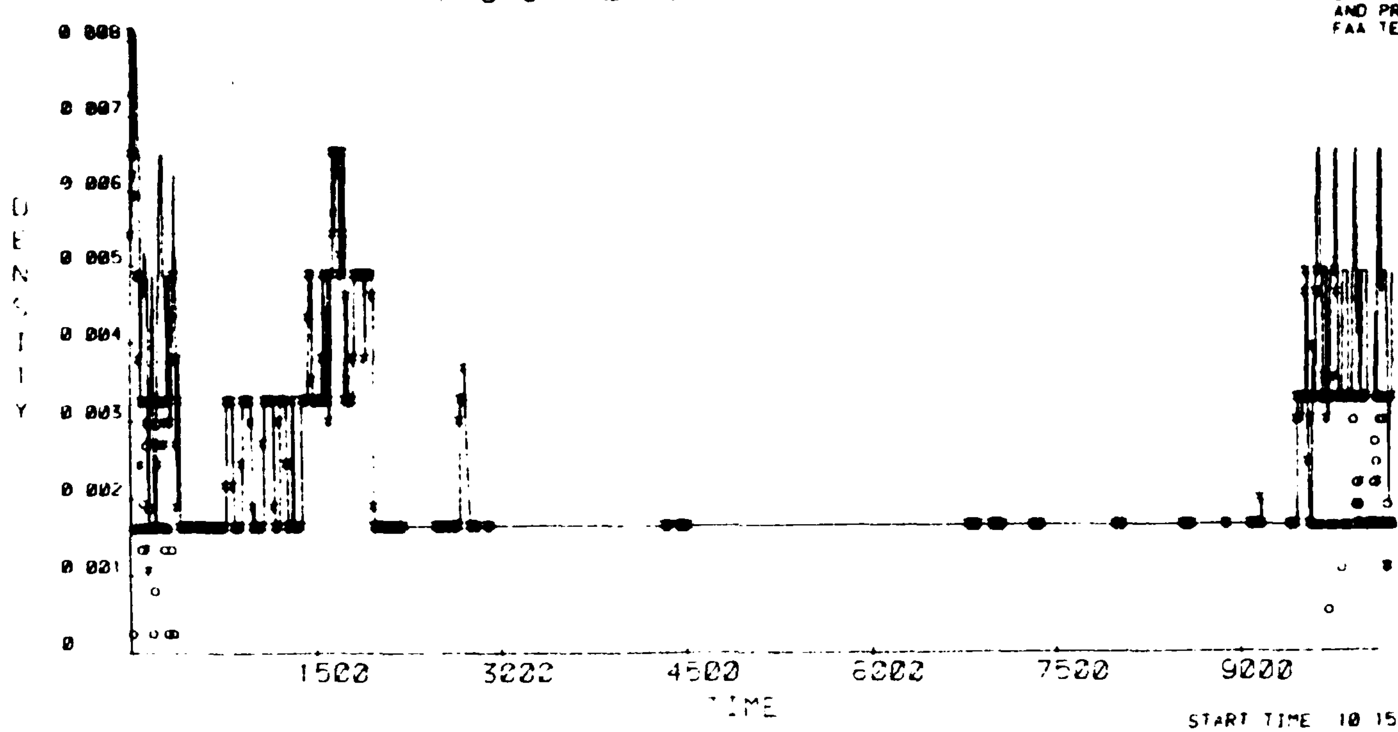

START TIME 10 15 20
STOP TIME 13 6 19

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 94	0 06	0	0	0	0	0
1	0 7	0	0 3	0	0	0	0
2	0 5	0	0	0 5	0	0	0
3	0 4	0	0	0	0 6	0	0
4	0 16	0	0	0	0	0 84	0
5	0 19	0	0	0	0	0	0 81
6	1 00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 85	0 15	0	0	0	0	0
1	0 63	0	0 37	0	0	0	0
2	0 45	0	0	0 55	0	0	0
3	0 22	0	0	0	0 78	0	0
4	0 17	0	0	0	0	0 83	0
5	0 13	0	0	0	0	0	0 87
6	1 00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME 10 15 20
STOP TIME 13 6 19

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 91%
NON MODE C 77%

PROCESSING DATE OCT 15,1984

NOTES

FLIGHT SUMMARY

MISSION 101183B.

Destination: Atlanta, GA

Flight Date: October 11, 1983

Mission Type: Approaches (12 completed)

Purpose: Medium density tracking evaluation

Departure: Hartsfield Airport, Atlanta 15:17:13

Arrival: Atlanta 17:07:10

Total Flight Time: 1 hour, 49 minutes, 57 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 8; Mode C = 8, includes 6 TA's and 2 RA's; Non-Mode C = 0

Advisories Eliminated by Piedmont Suppression Logic: 4; Mode C = 4, includes 4 TA's

Valid Advisories = 4; Mode C = 4, Non-Mode C = 0

Total Advisory Display Time: 123 seconds

Total Time Bearing was Invalid: 0 seconds (0%)

Problems Encountered in Flight = 1

Type: Engineering, a traffic advisory suppressed by the intruder-on-ground logic was displayed when the target was divergent and no longer a threat.

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Mode C	9s	-	25	No	708 ft	-	-	TAUR	Yes-1	Approach	1993	4	(1)
2.	TA-Mode C	4s	-	25	No	231 ft	-	-	TAUR	Yes-1	Approach	1750	4	(1)
3.	TA-Mode C	10s	-	34	No	387 ft	-	-	TAUR	Yes-1	Approach	1731	4	
4.	TA-Mode C	7s	-	34	No	643 ft	-	-	TAUR	Yes-1	Approach	1612	4	(2)
5.	TA-Mode C	15s	44.5s	12	No	-481 ft	see line 7		TAUR	No	Pattern	4000	5	(3)
6.	RA-DC	2s	30.5s	12	No	-668 ft	see line 7		TAUR	No	Pattern	4000	5	(4)
7.	RA-LC 500	29s	28.5s	12	No	-700 ft	0.69	-700	TAUR	No	Pattern	4000	5	(5)
8.	TA-Mode C	47.5s	45.5s	16	No	1000 ft	1.06	1000	TAURTA	No	Approach	2900	5	(6)

Notes:

(1) TA oscillation
(2) Logic error; *TA timer caused TA*
(3) Valid advisory
(4) Same A/C; TA turned to RA
(5) Same A/C; RA sense lessened
(6) Valid advisory; IFR separation

101183B

PROTOTYPE TEST FLIGHT 10/11/83-B

DATA RECORDED
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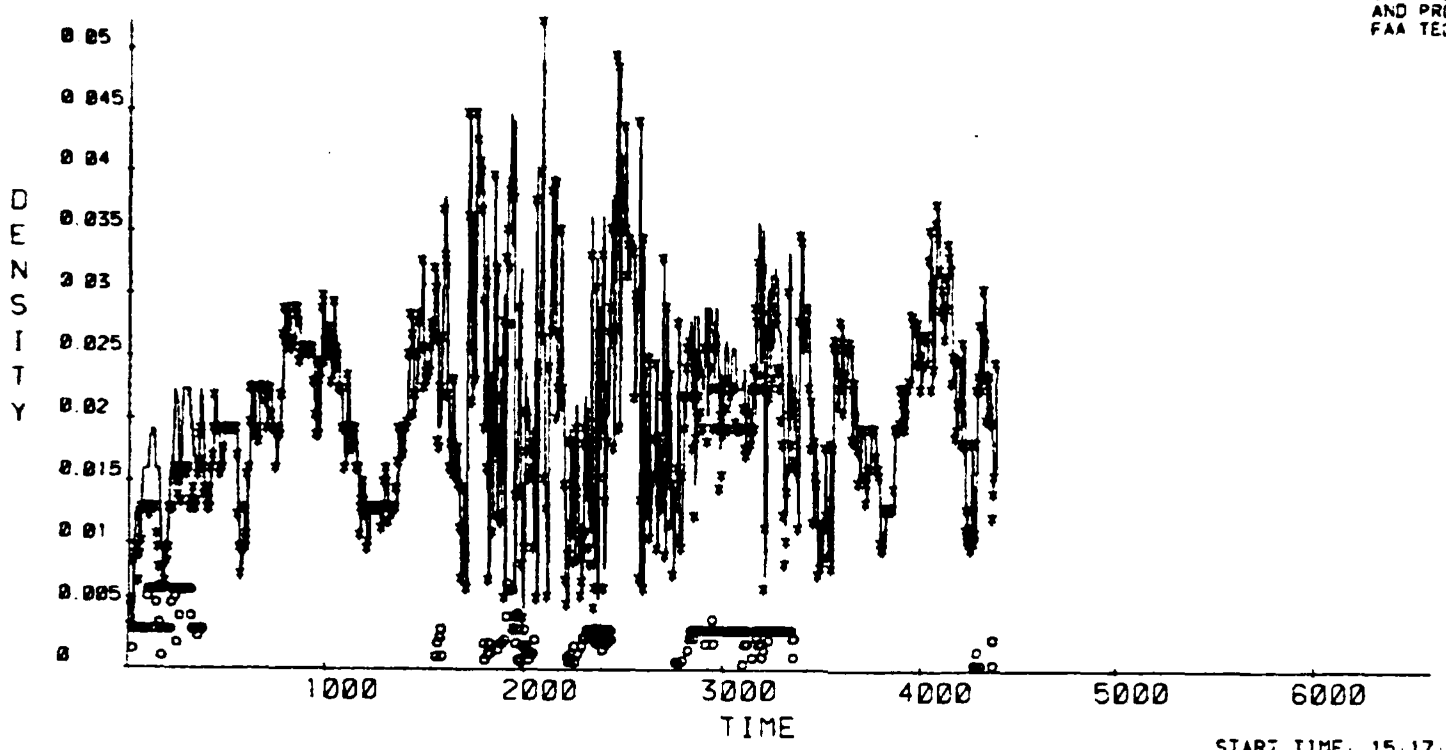


START TIME: 15:17:13
STOP TIME: 17: 7.10

MODE C MATRIX

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.92	0.08	0	0	0	0	0
1	0.75	0	0.25	0	0	0	0
2	0.57	0	0	0.43	0	0	0
3	0.39	0	0	0	0.61	0	0
4	0.25	0	0	0	0	0.75	0
5	0.16	0	0	0	0	0	0.84
6	1.00	0	0	0	0	0	0

START TIME: 15:17:10
STOP TIME: 16:30:27

NON MODE C MATRIX

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.87	0.13	0	0	0	0	0
1	0.68	0	0.32	0	0	0	0
2	0.6	0	0	0.41	0	0	0
3	0.35	0	0	0	0.65	0	0
4	0.18	0	0	0	0	0.82	0
5	0	0	0	0	0	0	1.00
6	1.00	0	0	0	0	0	0

LEGEND

MODE C	***
NON MODE C	ooo
TOTAL	——

UPDATE RATES

MODE C	89%
NON MODE C	83%

NOTES:

PROCESSING DATE: APRIL 8,1985

FLIGHT SUMMARY

MISSION 101883.

Destination: Philadelphia, PA

Flight Date: October 18, 1983

Mission Type: Approaches (seven completed)

Purpose: Medium density tracking evaluation

Departure: Technical Center (ACY) 11:52:00

Arrival: ACY 13:36:23

Total Flight Time: 1 hour, 44 minutes, 23 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 8; Mode C = 8, includes 6 TA's and 2 RA's; Non-Mode C = 0

Advisories Eliminated by Piedmont Suppression Logic: None

Valid Advisories = 8; Mode C = 8

Total Advisories Display Time: 167 seconds

Total Time Bearing was Invalid: 0

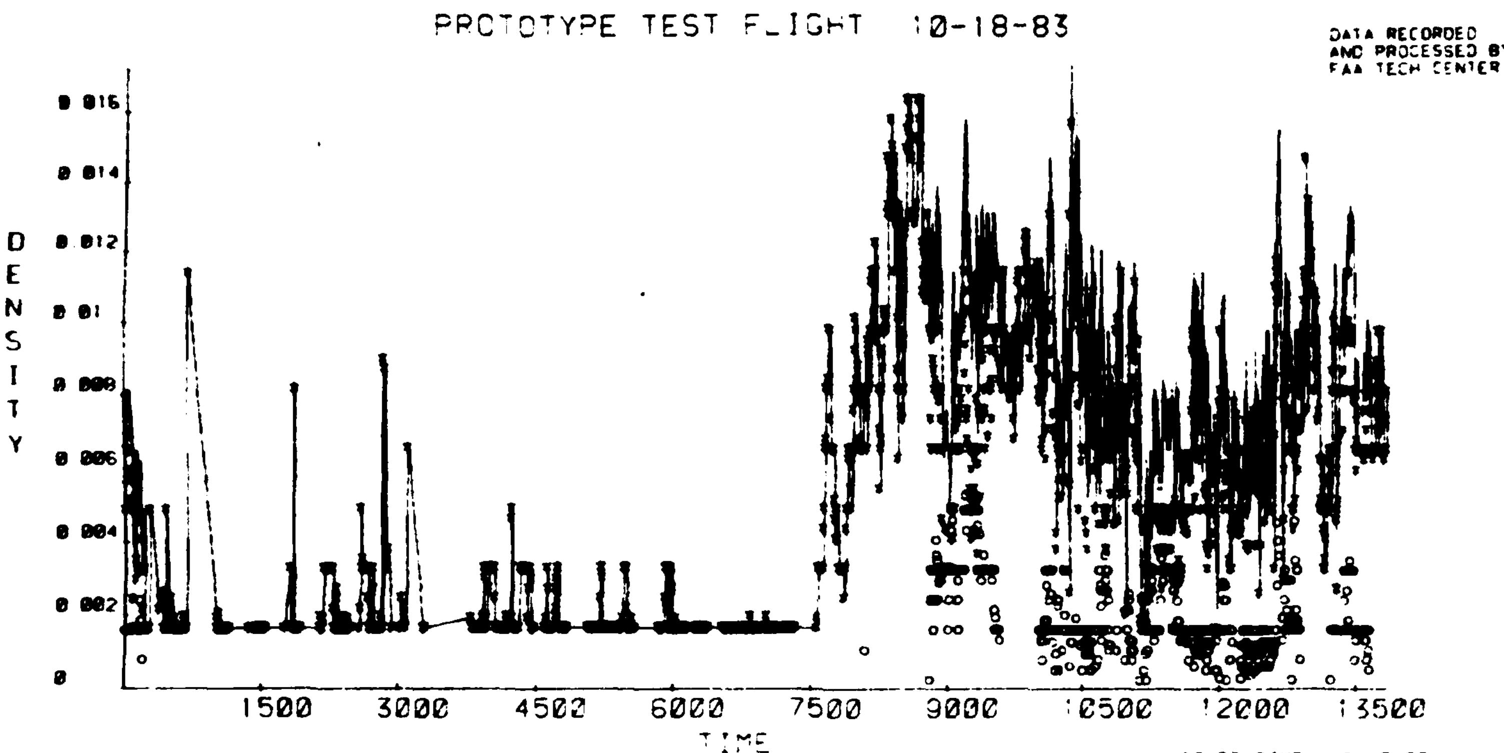
Problems Encountered in Flight: None

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (CPA)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Mode C	40s	36s	39	No	-1262 ft	[illegible]	[illegible]	TAUR	No	Approach	2350	5	
2.	RA-Climb	19s	13s	35	No	+63 ft	0.38	[illegible]	TAUR	No	Depart	450	4	(1)
3.	TA-Mode C	-	19s	36	No	same aircraft as line 2				No	Departure	868	4	
4.	TA-Mode C	39s	30s	16	No	1100 ft	2.03	1100	TAURTA	No	Pattern	3600	5	
5.	TA-Mode C	15s	13s	15	No	0 ft	0.22	800	TAURTA	No	Final	100	2	(2)
6.	TA-Mode C	34s	9s	23	No	662 ft	see line 7		TAURTA	No	Departure	1800	4	
7.	RA-Climb	20s	11s	23	No	562 ft	0.26	831	TAUR	No	Departure	1800	4	
8.	TA-Mode C		10s	23	No	same aircraft as line 7			TAURTA	No	Departure	1800	4	

Notes:

(1) Parallel departure
(2) Parallel departure

101883A



START TIME 9 45 20
STOP TIME 13 35 21

MODE C MATRIX — FUTURE COAST STATE (columns) / PRESENT COAST STATE (rows)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.88	0.12	0	0	0	0	0
1	0.72	0	0.28	0	0	0	0
2	0.56	0	0	0.44	0	0	0
3	0.4	0	0	0	0.6	0	0
4	0.29	0	0	0	0	0.71	0
5	0.16	0	0	0	0	0	0.84
6	1.00	0	0	0	0	0	0

MODE C MATRIX

NON MODE C MATRIX — FUTURE COAST STATE (columns) / PRESENT COAST STATE (rows)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.86	0.14	0	0	0	0	0
1	0.68	0	0.32	0	0	0	0
2	0.44	0	0	0.56	0	0	0
3	0.38	0	0	0	0.62	0	0
4	0.21	0	0	0	0	0.79	0
5	0.17	0	0	0	0	0	0.83
6	1.00	0	0	0	0	0	0

START TIME 9.45.20
STOP TIME 13.36.21

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 84%
NON MODE C 80%

PROCESSING DATE: OCT 15,1984

NOTES:

FLIGHT SUMMARY

MISSION 111583.

Destination: Philadelphia, PA

Flight Date: November 15, 1983

Mission Type: Approaches (six completed), part of the operational evaluation

Purpose: Subject pilot operational evaluation

Departure: Technical Center (ACY) 10:34:00

Arrival: ACY 12:11:11

Total Flight Time: 1 hour, 37 minutes, 11 seconds

TCAS Configuration: Same as mission 101183A, except two hardware problems corrected in acceptance test of 10/30/83:

1. Some bearing jitter eliminated
2. Microprocessor timing contention eliminated

SUMMARY DATA.

Total Advisories: 4; Mode C = 4, includes 3 TA's and 1 RA; Non-Mode C = 0

Advisories Eliminated by Piedmont Suppression Logic: None

Valid Advisories = 4

Total Advisory Display Time: 73 seconds

Total Time Bearing was Invalid = 1 second (1.4%)

Problems Encountered in Flight: Display control unit failure caused no IVSI presentation.

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Mode C	235s	255s	44	Yes (1s)	825 ft	0.88	1000	TAUR	No	En Route	3900	5	
2.	TA-Mode C	405s	375s	35	No	-1050 ft	see line 3		TAURTA	No	Approach	2980	5	
3.	RA-LC 500	205s	45s	35	No	see line 2	1.1	700	TAUR	No	Approach	2950	5	
4.	TA-Mode C	(divergent)	7s	35	No	TA following RA of line 3				No	Approach	2950	5	

111583

PROTOTYPE TEST FLIGHT 11-15-83

DATA RECORDED
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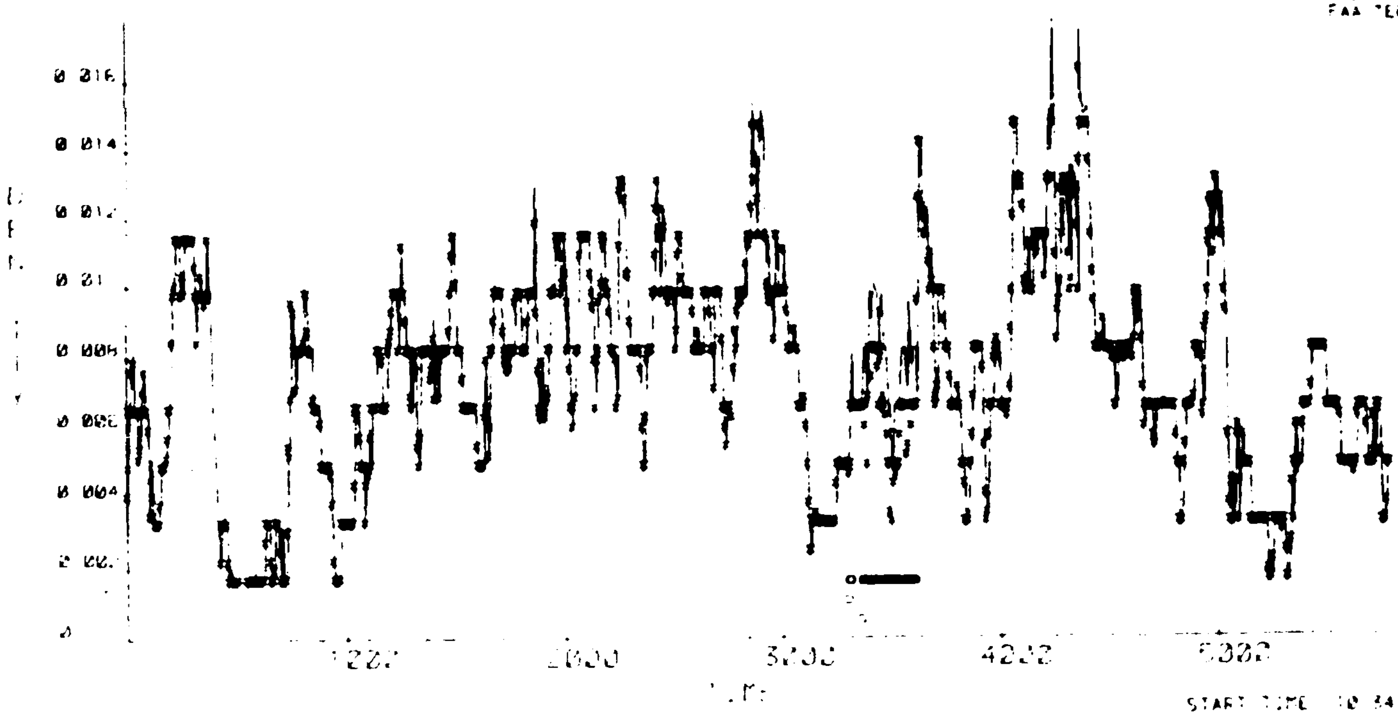

START TIME 10 34 11
STOP TIME 12 10 57

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.92	0.08	0	0	0	0	0
1	0	0	0.23	0	0	0	0
2	0.4[illegible]	0	0	0.54	0	0	0
3	0.75	0	0	0	0.25	0	0
4	0.23	0	0	0	0	0.[illegible]	0
5	0.[illegible]	0	0	0	0	0	0.8
6	[illegible]	0	0	0	0	0	0

MODE C MATRIX

START TIME 10 34 11
STOP TIME 12 12 57

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.8	0.2	0	0	0	0	0
1	0.[illegible]	0	0.28	0	0	0	0
2	0.55	0	0	0.46	0	0	0
3	0.2	0	0	0	0.6	0	0
4	0.5	0	0	0	0	0.5	0
5	0.5	0	0	0	0	0	0.5
6	[illegible]00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 88%
NON MODE C 76%

PROCESSING DATE OCT 15, 1984

NOTES

FLIGHT SUMMARY

MISSION 111883A.

Destination: Philadelphia (PHL)

Flight Date: November 18, 1983

Mission Type: Approaches (nine completed)

Purpose: Subject pilot operational evaluation

Departure: Technial Center (ACY) 09:43:53

Arrival: ACY 11:24:27

Total Flight Time: 1 hour, 40 minutes, 34 seconds

TCAS Configuration: Same as mission 111583

SUMMARY DATA.

Total Advisories: 29; Mode C = 6, includes 6 TA's and 0 RA's; Non-Mode C = 23

Advisories Eliminated by Piedmont Suppression Logic = 8; Mode C = 4, Non-Mode C = 4

Valid Advisories: 21; includes 2 Mode C TA's and 19 Non-Mode C TA's

(Note: flight observer's notes state that eight valid non-Mode C advisories were generated from an apparent parrot on the airfield.)

Total Advisory Display Time: 582 seconds

Total Time Bearing was Invalid: 9 seconds (1.5%)

Problems Encountered in Flight: None

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Non-Mode C	25s	285s	5	No	-	1.03	-	TAURTA	No	En Route	3850	5	(1)
2.	TA-Non-Mode C	18s	35s	31	No	-	0.19	-	TAURTA	No	Final	300 (Baro)	4	(2)
3.	TA-Non-Mode C	20s	35s	32	No	-	0.38	-	TAURTA	No	Departure	1750	4	
4.	TA-Non-Mode C	15s	30s	11	No	-	0.17	-	TAURTA	No	Final	160	2	
5.	TA-Mode C	-	165s	43	No	-	-	-	-	Yes-1	Departure	750	4	
6.	TA-Non-Mode C	-	3s	19	No	-	-	-	-	Yes-2	Pattern	1800	4	
7.	TA-Non-Mode C	13s	15s	37	No	-	0.34	-	TAURTA	No	Final	525	4	
8.	TA-Mode C	-	9s	34	No	-	-	-	-	Yes-1	Final	760	4	
9.	TA-Mode C	-	14s	13	No	-	-	-	-	Yes-1	Final	760	4	
10.	TA-Non-Mode C	18s	5s	32	Yes (1s)	-	1.57	-	TAURTA	No	Final	350	4	
11.	TA-Non-Mode C	18s	33s	20	No	-	0.21	-	TAURTA	No	Final	-31 (Baro)	2	(3)
12.	TA-Mode C	-	14s	24	No	-	-	-	-	Yes-1	Departure	760	4	
13.	TA-Non-Mode C	15s	31s	31	No	-	0.21	-	TAURTA	No	Final	470 (Baro)	4	(4)
14.	TA-Non-Mode C	20s	40s	29	No	-	0.26	-	TAURTA	No	Final	420	4	
15.	TA-Non-Mode C	23s	27s	0	No	-	0.29	-	TAURTA	No	Departure	620	4	
16.	TA-Non-Mode C	-	15	19	Yes (1s)	-	-	-	-	Yes-2	Departure	1170	4	
17.	TA-Non-Mode C	19s	35s	11	No	-	0.20	-	TAURTA	No	Final	420 (Baro)	4	(5)
18.	TA-Non-Mode C	20s	25	41	No	-	0.50	-	TAURTA	No	Departure	800	4	
19.	TA-Non-Mode C	19s	15s	15	No	-	0.25	-	TAURTA	No	Final	550	4	
20.	TA-Non-Mode C	No data	4s	[illegible]	No	-	[illegible]	-	No data	No	Departure	950	4	

[illegible] - Page [illegible]

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
21.	TA-Non-Mode C	No Data	11s	40	No	-	0.37	-	No Data	No	Departure	1160	4	
22.	TA-Non-Mode C	-	4s	25	No	-	-	-	-	Yes-2	Departure	1406	5	
23.	TA-Mode C	38s	33s	3	No	-468 ft	1.85	-532	TAURTA	No	En Route ACY	4900	5	
24.	TA-Non-Mode C	25s	14s	23	No	-	1.31	-	TAURTA	No	En Route ACY	4800	5	
25.	TA-Non-Mode C	25s	21s	27	No	-	1.34	-	TAURTA	No	En Route ACY	4800	5	
26.	TA-Non-Mode C	-	35s	40	No	-	-	-	-	Yes-2	En Route ACY	4900	5	
27.	TA-Non-Mode C	25s	29s	26	No	-	0.8	-	TAURTA	No	En Route ACY	4900	5	
28.	TA-Non-Mode C	25s	45s	42	Yes (1 sec)	-	0.18	-	TAURTA	No	En Route ACY	4900	5	
29.	TA-Mode C	35s	7s	25	Yes (7 sec)	925 ft	2.2	800	TAURTA	No	Final ACY	1100	4	

Notes:

(1) TA leaving ACY
(2) Radar Alt = 531 ft
(3) Radar Alt = 210 ft
(4) Radar Alt = 637 ft
(5) Radar Alt = 581 ft

PROTOTYPE TEST FLIGHT 11-18-83

DATA RECORDED
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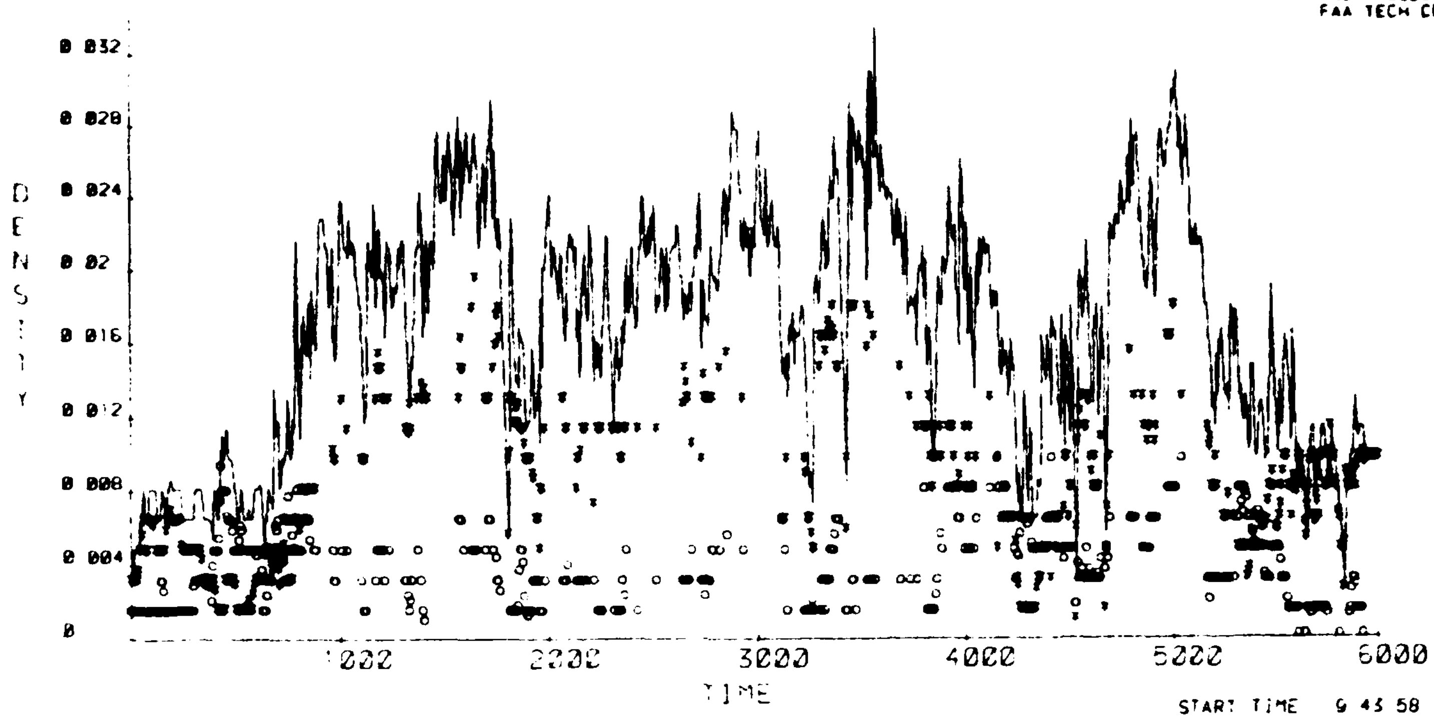

START TIME 9 43 58
STOP TIME 11 24 12

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 92	0 08	0	0	0	0	0
1	0 76	0	0 24	0	0	0	0
2	0 62	0	0	0 38	0	0	0
3	0 36	0	0	0	0 64	0	0
4	0 26	0	0	0	0	0 75	0
5	0 17	0	0	0	0	0	0 83
6	1 00	0	0	0	0	0	0

MODE C MATRIX

START TIME 9 43 58
STOP TIME 11 24 12

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 92	0 08	0	0	0	0	0
1	0 77	0	0 23	0	0	0	0
2	0 43	0	0	0 55	0	0	0
3	0 34	0	0	0	0 66	0	0
4	0 25	0	0	0	0	0 75	0
5	0 11	0	0	0	0	0	0 89
6	1 00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL —

UPDATE RATES

MODE C 89%
NON MODE C 88%

PROCESSING DATE OCT 15, 1984

NOTES

FLIGHT SUMMARY

MISSION 112983B.

Destination: Philadelphia, PA

Flight Date: November 29, 1983

Mission Type: Approaches (eight completed)

Purpose: Subject pilot operational evaluation

Departure: Technial Center (ACY) 13:30:54

Arrival: ACY 15:29:50

Total Flight Time: 1 hour, 59 minutes, 56 seconds.

SUMMARY DATA.

Total Advisories: 22; Mode C = 15, includes 15 TA's and 0 RA's; Non-Mode C = 7

Advisories Eliminated by Piedmont Suppression Logic = 10; Mode C = 10, Non-Mode C = 3

Valid Advisories = 12; includes 5 Mode C and 7 Non-Mode C

Total Advisory Display Time: 354 seconds

Total Time Bearing was Invalid: 4 seconds (1.1%)

Problems Encountered in Flight: None

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Mode C	12s	-	36	No	-	-	-	DMOD	Yes-1	Departure	1060	4	
2.	TA-Mode C	20s	29s	30	No	-837 ft	1.76	1100	TAURTA	No	Pattern	2200	4	
3.	TA-Mode C	7s	-	28	No	-	-	-	DMOD	Yes-1	Departure	1060	4	
4.	TA-Mode C	31s	20s	36	No	-425 ft	0.37	919	TARUTA	No	Departure	500	4	(1)
5.	TA-Mode C	15s	-	7	No	-	-	-	TAUR	Yes-1	Departure	1060	4	
6.	TA-Non-Mode C	6s	16s	15	No	-	0.31	-	No Data	No	Departure	1300	4	
7.	TA-Non-Mode C	6s	18s	33	No	-	See Line 8		TARUTA	No	Pattern	2250	4	(2)
8.	TA-Non-Mode C	13s	Line 7	36	No	-	0.74	-	TAURTA	No	Pattern	2250	4	(2)
9.	TA-Non-Mode C	13s	53s	31	No	-	0.45	-	DMOD	No	Pattern	1512	4	
10.	TA-Non-Mode C	31s	19s	14	No	-	0.34	-	-	No	Depart	1250	4	
11.	TA-Mode C	32s	35s	6	No	968 ft	1.21	932	TAURTA	No	Approach	2260	4	
12.	TA-Mode C	7s	-	4	No	-	-	-	TAUR	Yes-1	Departure	1060	4	
13.	TA-Mode C	17s	-	33	No	-	-	-	TAUR	Yes-1	Departure	1060	4	
14.	TA-Mode C	23s	31s	23	No	1312 ft	0.7	1300	TAURTA	No	Departure	1550	4	
15.	TA-Non-Mode C	3s	Line 5	27	Yes (3 sec)	-	Line 16	-	TAURTA	No	Pattern	2250	4	(3)
16.	TA-Non-Mode C	13s	-	5	No	-	0.49	-	Line 15	No	Pattern	2250	4	(3)
17.	TA-Mode C	13s	-	9	No	-	-	-	TAUR	Yes-1	Departure	1060	4	
18.	TA-Mode C	11s	-	5	No	-	-	-	TAUR	Yes-1	Departure	1060	4	
19.	TA-Non-Mode C	9s	-	40	No	-	-	-	TAURTA	Yes-1	Departure	1160	4	
20.	TA-Mode C	13s	[illegible]	37	No (1sec)	-	-	-	TAUR	Yes-1	Departure	1060	4	

[illegible] - Page [illegible] of 2

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
21. TA-Mode C	-	14s	19	No	-	-	-	TAUR	Yes-1	Departure	1020	4	
22. TA-Mode C	34s	45s	27	Yes (1 sec)	-1187 ft	0.1	-1100	TAURTA	No	Final-ACY	2250	4	(4)

Notes:

(1) TA would not cause altitude cross
(2) TA sequence interrupted by track ID change
(3) RA sequence interrupted by track ID change
(4) TCAS underflew head-on intruder

PROTOTYPE TEST FLIGHT 11-29-83

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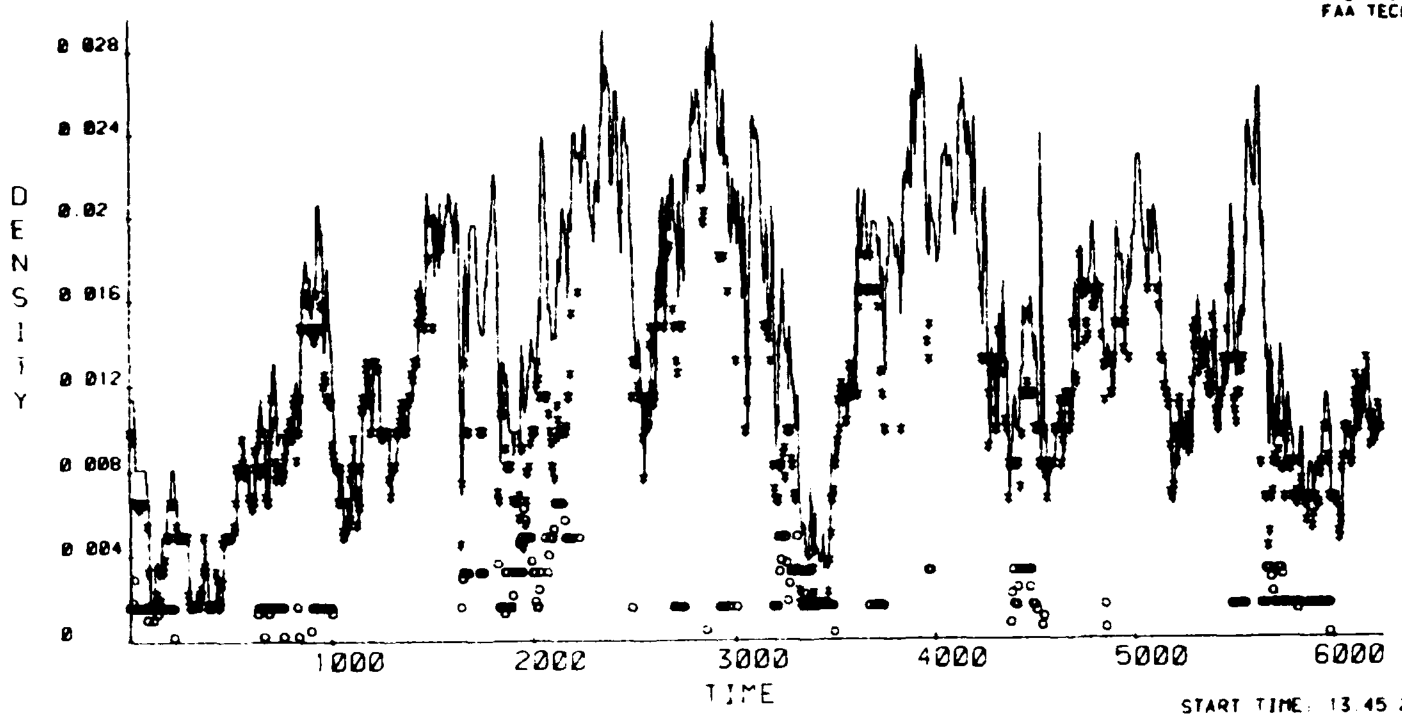


START TIME: 13.45.20
STOP TIME 15.29.36

MODE C MATRIX (FUTURE COAST STATE across, PRESENT COAST STATE down)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.92	0.08	0	0	0	0	0
1	0.75	0	0.25	0	0	0	0
2	0.46	0	0	0.51	0	0	0
3	0.33	0	0	0	0.67	0	0
4	0.23	0	0	0	0	0.77	0
5	0.13	0	0	0	0	0	0.88
6	1.00	0	0	0	0	0	0

START TIME 13.45.20
STOP TIME 15.29.36

NON MODE C MATRIX (FUTURE COAST STATE across, PRESENT COAST STATE down)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.9	0	0	0	0	0	0
1	0.65	0	0.35	0	0	0	0
2	0.39	0	0	0.61	0	0	0
3	0.31	0	0	0	0.69	0	0
4	0.25	0	0	0	0	0.75	0
5	0.12	0	0	0	0	0	0.88
6	.00	0	0	0	0	0	0

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 89%
NON MODE C 84%

PROCESSING DATE: OCT 15, 1984

NOTES:

FLIGHT SUMMARY

MISSION 113083.

Destination: Newark (EWR)

Flight Date: November 30, 1983

Mission Type: Approaches

Purpose: Approach mission, subject pilot operational evaluation

Departure: FAA Technical Center (ACY) 14:00:32

Arrival: ACY 15:58:38

Total Flight Time: 1 hour, 58 minutes, 6 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 13; Mode C = 8 TA's, Non-Mode C = 5 TA's

Advisories Eliminated by Piedmont Suppression Logic = 0

Valid Advisories = 13

Total Bearing Display Time: 205 seconds

Total Time Bearing was Invalid: 0 second (0%)

Problems Encountered in Flight: Two engineering problems.

1. Data overflow caused TCAS failure and burst of audio
2. TA against aircraft 1200 feet below (not included in above statistics)

Both problems are fixed as of February 1984.

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Non-Mode C	31s	25s	12	No	0 ft	0.29	-	TAURTA	No		5000	5	
2. TA-Mode C	14s*	17s*	37	No	-5693 ft	0.74	-	TAURTA	No	Approach	193	2	(1)
3. TA-Mode C	1s*	17s	2	No	-1262 ft	*	*	TAURTA	No	Approach	481	2	
4. TA-Mode C	35s	17s	15	No	193 ft	*	*	TAURTA	No		4000	5	
5. TA-Non-Mode C	9s*	23s*	25	NO	0 ft	0.90	-	TAURTA	No		2900	5	
6. TA-Mode C	12s*	23s	24	No	137 ft	1.00	2894	TAURTA	No		2900	5	
7. TA-Mode C	18s*	16s*	10	No	-531 ft	0.45	475	TAURTA	No		487	4	
8. TA-Mode C	12s	12s	27	No	1381 ft	0.33	1243	TAUR	No		918	4	(2)
9. TA-Mode C	12s	31s	33	No	2418 ft	0.73	1706	TAURTA	No		918	4	(2)
10. TA-Mode C	13s	32s	21	No	2293 ft	0.75	1556	TAUR	No		918	4	(2)
11. TA-Non-Mode C	8s	24s	35	No	0 ft	-	-	TAURTA	No		4500	5	(3)
12. TA-Non-Mode C	24s	24s	35	No	0 ft	0.89	-	TAURTA	No		4500	5	(3)
13. TA-Non-Mode C	16s	16s	5	No	0 ft	0.18	-	TAURTA	No		0	5	(4)

* Data Loss

Notes:

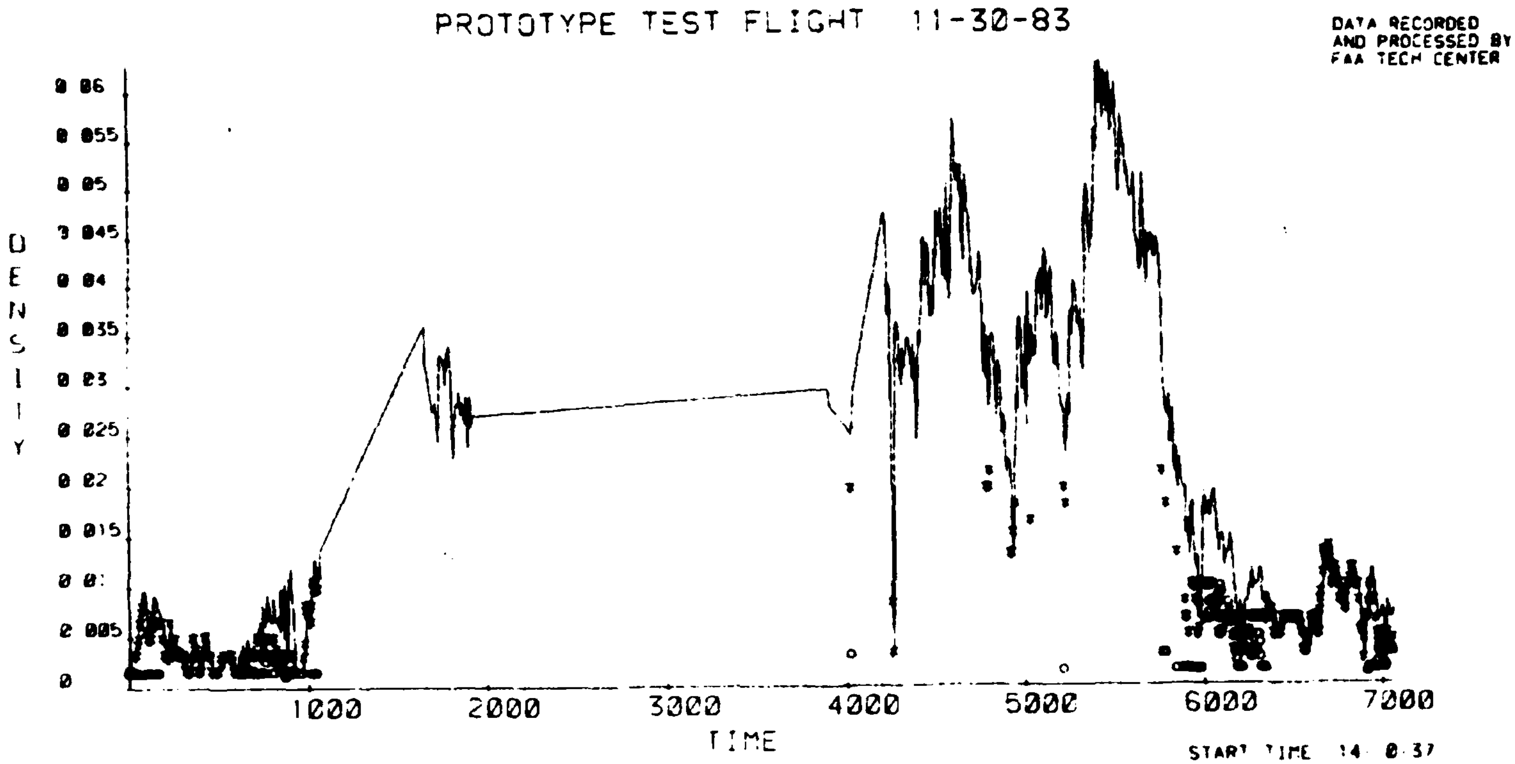
(1) Track No. 2 this TA was caused by a coding error in the software and was corrected (reference trouble report No. 21).

(2) Tracks 8, 9, and 10 were determined to be on ground prior to the TA's - the three TA's came up together when TCAS exceeded the threshold (850 feet) for calculating "on the ground."

(3) Tracks 11 and 12 are the same aircraft, however, the TA code dropped for 1 second.

(4) Track 13 terminated when TCAS on ground (PL=1).

113083



START TIME 14 0.37
STOP TIME 15 58 25

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.91	0.09	0	0	0	0	0
1	0.69	0	0.31	0	0	0	0
2	0.52	0	0	0.48	0	0	0
3	0.39	0	0	0	0.61	0	0
4	0.26	0	0	0	0	0.74	0
5	0.14	0	0	0	0	0	0.86
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME 14: 0.37
STOP TIME 15:58 25

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.91	0.09	0	0	0	0	0
1	0.62	0	0.38	0	0	0	0
2	0.35	0	0	0.65	0	0	0
3	0.1	0	0	0	0.9	0	0
4	0.26	0	0	0	0	0.75	0
5	0.11	0	0	0	0	0	0.89
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL —

UPDATE RATES

MODE C 87%
NON MODE C 83%

PROCESSING DATE OCT 15, 1984

NOTES

FLIGHT SUMMARY

MISSION 120683.

Destination: Minneapolis, MN

Flight Date: December 6, 1983

Mission Type: Typical operation from ACY-MSP

Purpose: TCAS demonstration, national tour

Departure: FAA Technical Center (ACY) 09:51:16

Arrival: MSP 12:12:45

Total Flight Time: 2 hours, 21 minutes, 29 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 2; Mode C = 2 TA's

Advisories Eliminated by Piedmont Suppression Logic = 0

Valid Advisories = 2

Total Bearing Display Time: 31 seconds

Total Time Bearing was Invalid: 0 second (0%)

Problems Encountered in Flight: None

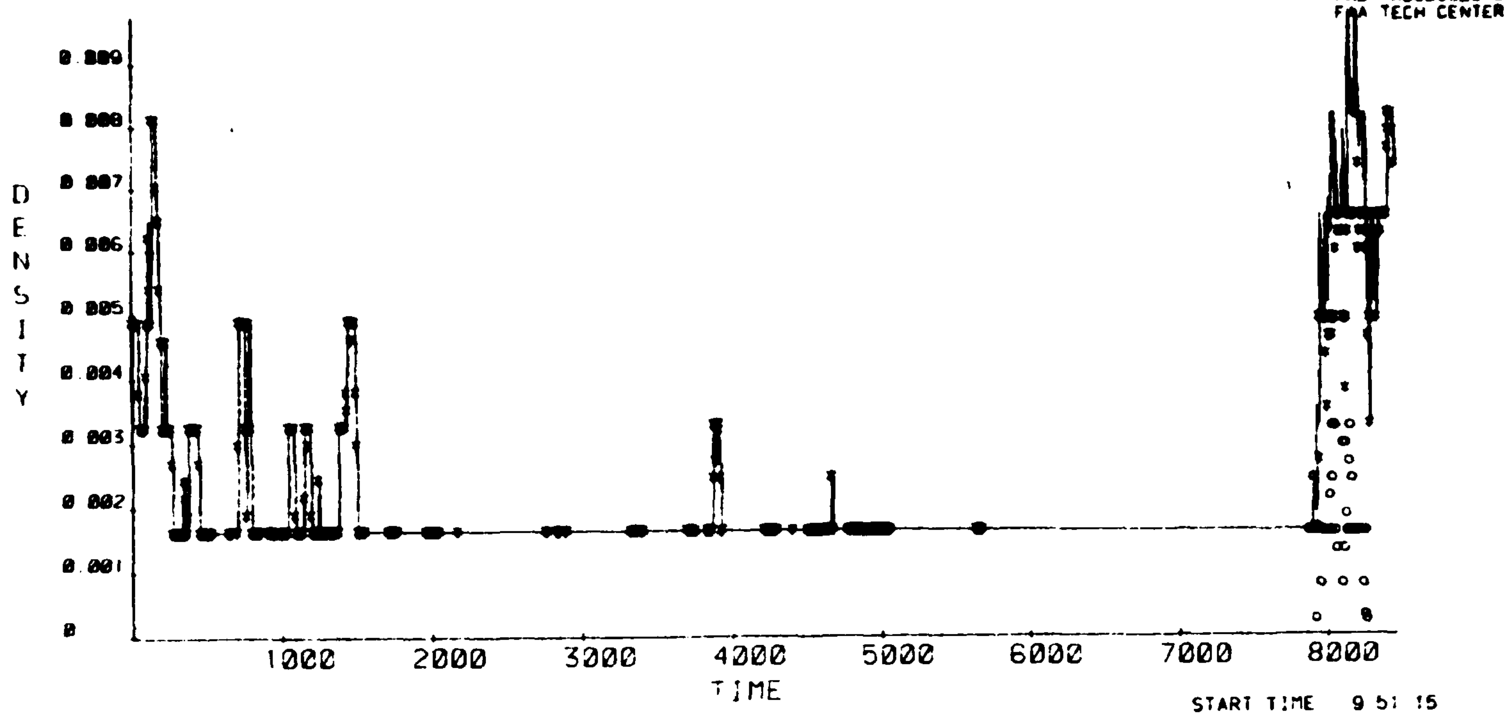
Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Mode C	13s	10.5s	7	No	-2543 ft	2.55	-	TAURTA	No	En Route	22962	6	
2. TA-Mode C	18s*	15s	29	No	-	0.62	-93	TAURTA	No	Approach	768	2	

* Data loss -Data not recorded.

120683

PROTOTYPE TEST FLIGHT 12-6-83

DATA RECORDED AND PROCESSED BY FAA TECH CENTER



START TIME 9 51 15
STOP TIME 12 12.33

	FUTURE COAST STATE						
PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.95	0.05	0	0	0	0	0
1	0.7	0	0.3	0	0	0	0
2	0.4	0	0	0.6	0	0	0
3	0.28	0	0	0	0.72	0	0
4	0.18	0	0	0	0	0.82	0
5	0.15	0	0	0	0	0	0.85
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME: 9.51.15
STOP TIME: 12 12.33

	FUTURE COAST STATE						
PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.8	0.2	0	0	0	0	0
1	0.55	0	0.45	0	0	0	0
2	0.35	0	0	0.65	0	0	0
3	0.27	0	0	0	0.73	0	0
4	0.18	0	0	0	0	0.82	0
5	0	0	0	0	0	0	1.00
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 91%
NON MODE C 68%

PROCESSING DATE: OCT 15, 1984

NOTES:

FLIGHT SUMMARY

MISSION 120783.

Destination: Minneapolis, MN

Flight Date: December 7, 1983

Mission Type: Approaches, five Completed

Purpose: TCAS demonstration, national tour

Departure: MSP 10:45:20 (morning flight); 12:29:58 (afternoon flight)

Arrival: MSP 12:01:00 (morning flight); 13:23:00 (afternoon flight)

Total Flight Time: 2 Hours, 8 Minutes, 42 Seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 13; Mode C = 12 TA's, Non-Mode C = 1

Advisories Eliminated by Piedmont Suppression Logic = 0

Valid Advisories = 13

Total Bearing Display Time: 268 seconds

Total Time Bearing was Invalid: 0 seconds (0%)

Problems Encountered in Flight: None

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Mode C	15s*	19s*	3	No		0.44	1712	TAURTA	No	Approach	1450	4 6	Coast Out
2. TA-Mode C	10s	-	7	No	962 ft	0.40	893	RTHRTA	No	Approach	1762	4	(1)
3. TA-Mode C	14s	3s	40	No	1275 ft	3.52	1269	TAURTA	No	Pattern	3900	5	
4. TA-Mode C	8s	-	26	No	1031 ft	.15	875	(NOTE 2)	No	Approach	1762	4	(2)
5. TA-Mode C	32s	39s	31	No	212 ft	1.79	431	TAURTA	No	Pattern	3381	5	IOG SET Prior to TA
6. TA-Mode C	15s	25s	41	No	1862 ft	0.92	1156	TAURTA	No	Approach	1768	4	
7. TA-Non-Mode C	15s	24s	26	No	-	1.12	-	TAURTA	No	Pattern	3900	5	(3)
8. TA-Mode C	18s	8s	14	No	1250 ft	0.17	1187	TAUR	No	Approach	1768	4	IOG SET Prior to TA
9. TA-Mode C	12s	14s	26	No	1418 ft	0.67	1112	TAURTA	No	Approach	1762	4	IOG SET Prior to TA
10. TA-Mode C	14s	9s	17	No	1187 ft	0.15	1368	TAUR	No	Approach	1706	4	IOG SET Prior to TA
11. TA-Mode C	58s	39s	7	No	968 ft	0.72	900	TAURTA	No	Approach	3900	5	(4)
12. TA-Mode C	48s	33s	27	No	337 ft	0.03	877	TAURTA	No	Pattern	3237	4	
13. TA-Mode C	9s	44s	10	No	393 ft	2.62	2032	TAUR	No	Enroute	9756	6	

* - Data Not Recorded

Notes:

(1) When our radar altimeter exceeded 850 ft, the "on the ground" calculation ceased. At this point the intruder was diverging, however, it was within immediate TA range threshold (RTHRTA). It was also within the range - range rate threshold (HITA). CPA occurred just prior to the FA and "on the ground was active.

(2) [illegible] occurred 6s prior to the TA when "on the ground" logic was active. Intruder diverging, HITA threshold not satisfied.

(3) Track coasted out probably prior to CPA, CAS track started 5s prior to TA.

(4) [illegible]

PROTOTYPE TEST FLIGHT 12-7-83A

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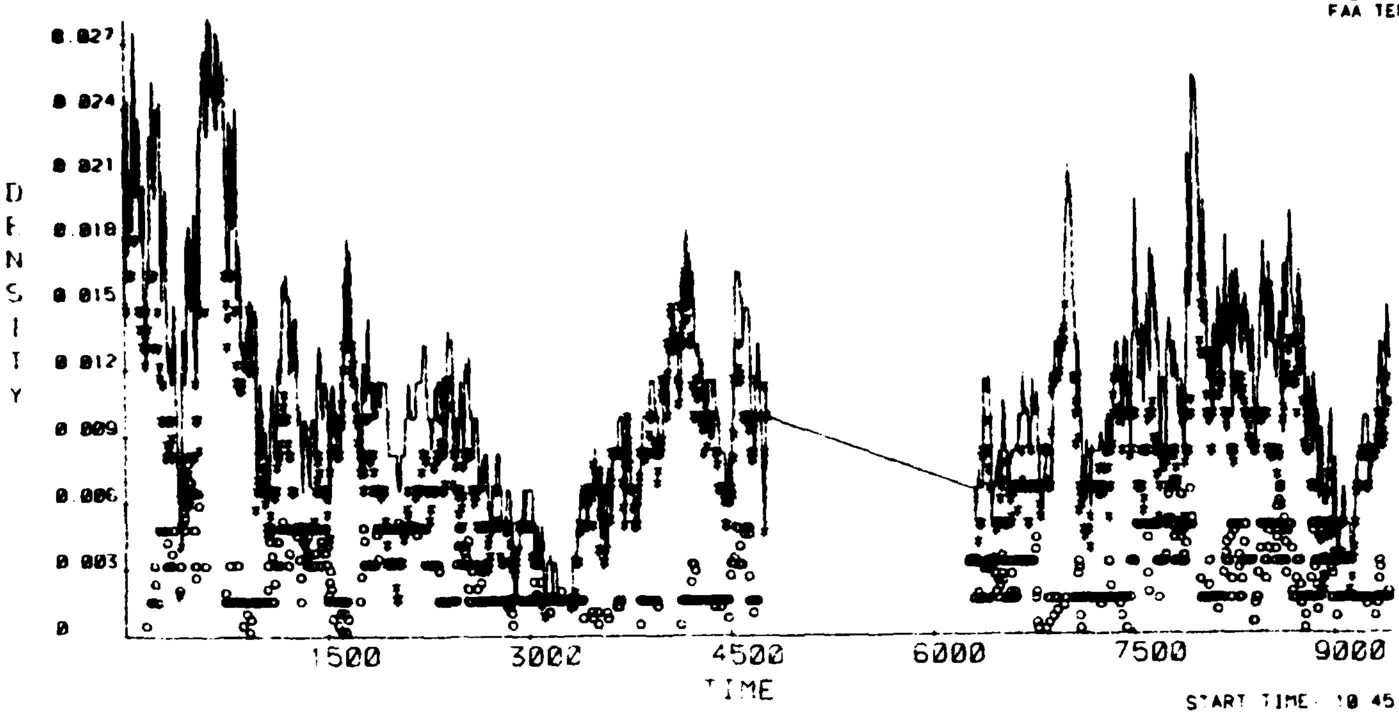


START TIME 10 45 9
STOP TIME 13 22 27

MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.92	0.08	0	0	0	0	0
1	0.71	0	0.29	0	0	0	0
2	0.46	0	0	0.54	0	0	0
3	0.33	0	0	0	0.67	0	0
4	0.25	0	0	0	0	0.75	0
5	0.18	0	0	0	0	0	0.83
6	1.00	0	0	0	0	0	0

START TIME 10 45 9
STOP TIME 13 22 27

NON MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.87	0.13	0	0	0	0	0
1	0.64	0	0.36	0	0	0	0
2	0.49	0	0	0.51	0	0	0
3	0.28	0	0	0	0.71	0	0
4	0.21	0	0	0	0	0.79	0
5	0.18	0	0	0	0	0	0.82
6	1.00	0	0	0	0	0	0

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

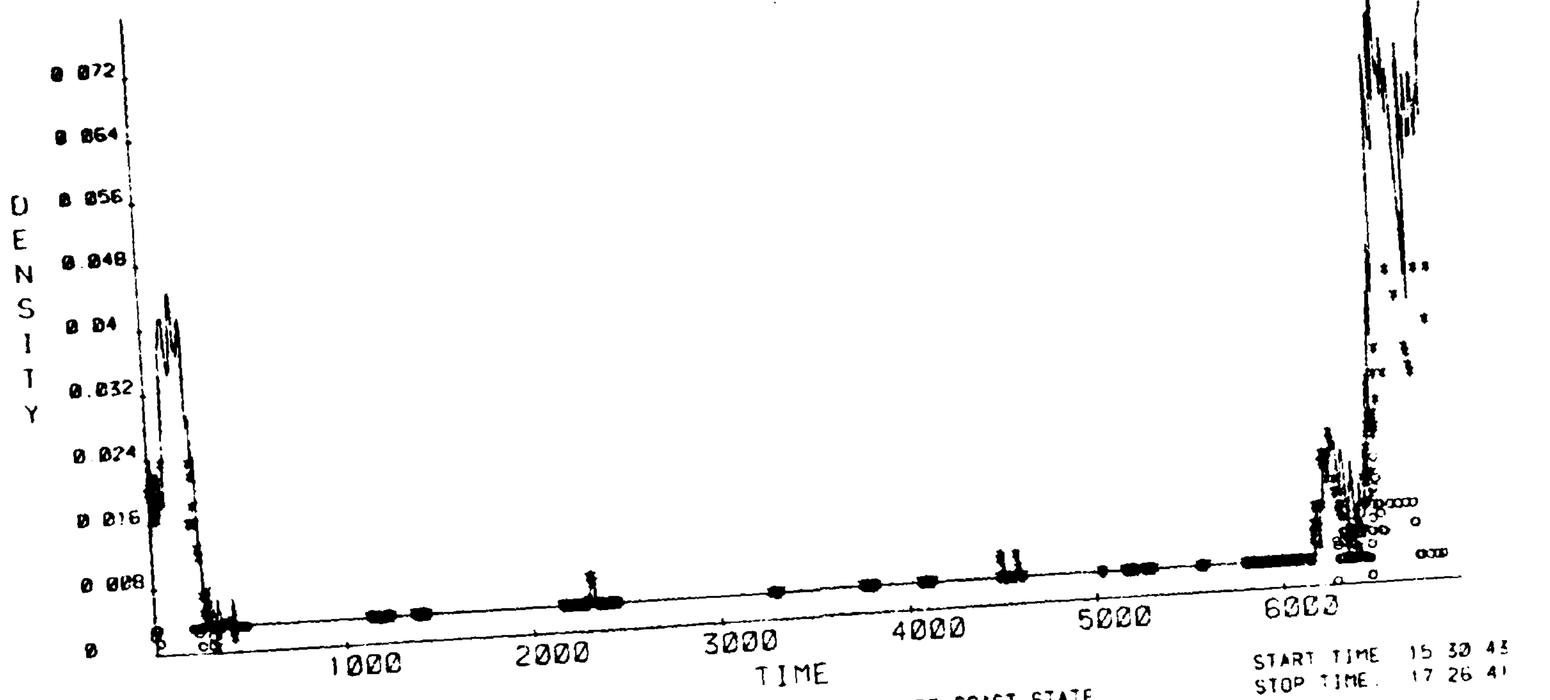
UPDATE RATES

MODE C 88%
NON MODE C 80%

PROCESSING DATE OCT 15, 1984

NOTES

PROTOTYPE TEST FLIGHT 12-7-83B



START TIME 15 30 43
STOP TIME 17 26 41

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ---

UPDATE RATES

MODE C 83%
NON MODE C 78%

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.9	0.1	0	0	0	0	0
1	0.61	0	0.39	0	0	0	0
2	0.37	0	0	0.63	0	0	0
3	0.32	0	0	0	0.67	0	0
4	0.28	0	0	0	0	0.72	0
5	0.11	0	0	0	0	0	0.89
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME. 15.30.43
STOP TIME. 17.26.41

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.86	0.14	0	0	0	0	0
1	0.64	0	0.36	0	0	0	0
2	0.33	0	0	0.67	0	0	0
3	0.28	0	0	0	0.72	0	0
4	0.14	0	0	0	0	0.86	0
5	0.06	0	0	0	0	0	0.94
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

PROCESSING DATE. OCT 30.1984

NOTES.

FLIGHT SUMMARY

MISSION 120883A.

Destination: Dallas/Fort Worth (DFW)

Flight Date: December 8, 1983

Mission Type: Approaches (seven completed)

Purpose: National tour demonstration

Departure: DFW 10:45:03

Arrival: DFW 12:26:40

Total Flight Time: 1 hour, 41 minutes, 37 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 25; Mode C = 17, includes 14 TA's and 3 RA's; Non-Mode C = 8

Advisories Eliminated by Piedmont Suppression Logic: Mode C = 4, Non-Mode C = 0

Valid Advisories: 21

Total Advisory Display Time: 400 seconds

Total Time Bearing was Invalid: 9 seconds (2.3%)

Problems Observed in Flight: Engineering; observed a 30° bearing jump on the TA in line No. 20 (Track ID = 10)

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Range	Miss Alt	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA Non-Mode C	21s	25s	12	No	-	1.24		TAURTA	No	Pattern	3700	5	
2. TA Non-Mode C	8s	15s	8	No	-	0.56		TAURTA	No	Approach	1200	4	
3. TA-Mode C	24s	23s	38	No	600 ft	See line 4		TAURTA	No	Approach	3500	5	
4. RA-LD 1000	4s	6s	38	No	738 ft	0.56	738	DMOD	No	Approach	3000	5	
5. TA-Mode C	6s	-	38	No	-	See line 4		TAURTA	No	Approach	2860	4	(1)
6. TA-Mode C	11s	35s	38	No	-1156 ft	1.09	-794	TAURTA	No	Approach	1600	4	
7. TA-Mode C	2S	-	3	No	-	-	-	TAUR	Yes-1	Approach	1260	4	
8. TA-Mode C	10s	-	5	Yes (1s)	-	-	-	TAURTA	Yes-1	Departure	1450	4	
9. TA-Mode C	17s	34s	20	No	-481 ft	1.37	-300	TAURTA	No	Departure	2250	4	
10. TA-Mode C	8s	-	24	No	-	-	-	TAUR	Yes-1	Approach	1260	4	
11. TA-Mode C	7s	-	18	Yes (6s)	-	-	-	TAURTA	Yes-1	Approach	1360	4	
12. TA-Mode C	41s	34s	19	No	-1000 ft	0.38	-1032	TAURTA	No	Pattern	2800	4	
13. TA-Mode C	1s	-	3	No	-	-	-	DMOD	No	Final	560	2	(2)
14. TA-Mode C	4s	-	17	No	-	-	-	DMOD	No	Final	560	2	(3)
15. TA Non-Mode C	49s	34s	6	No	-	0.53	-	TAURTA	No	Pattern	3560	5	
16. TA-Mode C	45s	38s	44	No	1100 ft	1.54		TAURTA	No	Pattern	3800	5	
17. TA-Non-Mode C	26s	25s	25	No	-	0.87	-	TAURTA	No	Pattern	3800	5	
18. TA-Non-Mode C	3s	21s	33	Yes (2s)	-	1.85	-	TAURTA	No	Pattern	3800	5	

120883A - Page 1 of 2

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
19.	TA-Non-Mode C	18s	22s	37	No	-	0.97	-	TAURTA	No	Pattern	3800	5	
20.	TA-Non-Mode C	27s	39s	10	No	-268 ft	1.95	1000	TAURTA	No	Pattern	2900	5	
21.	TA-Mode C	13s	39s	38	No	743 ft	See Line 23		TAURTA	No	Pattern	2800	4	(4)
22.	RA-LD 500	10s	21s	38	No	743 ft	See Line 23		TAUR	No	Pattern	2800	5	
23.	RA-LD 1000	15s	15s	38	No	700 ft	0.57	619	TAUR	No	Pattern	2800	5	
24.	TA-Mode C	5s	-	-	No	-	-	-	TAURTA	No	Pattern	2800	5	(5)
25.	TA-Non-Mode C	25s	20s	28	No	-	0.76	-	TAURTA	No	Pattern	2800	4	(6)

Notes:

(1) TA after the RA

(2) Intruder on ground detection foiled by intruder's altimeter; reads 100 feet hi

(3) Intruder on ground detection foiled by intruder's altimeter; reads 100 feet hi

(4) Radar Altimeter = 2312 feet, caused PL 4

(5) TA after the RA

(6) Radar Altitude = 2418 feet; caused PL 4

120883A - Page 2 of 2

PROTOTYPE TEST FLIGHT 12-8-83A

DATA RECORDED
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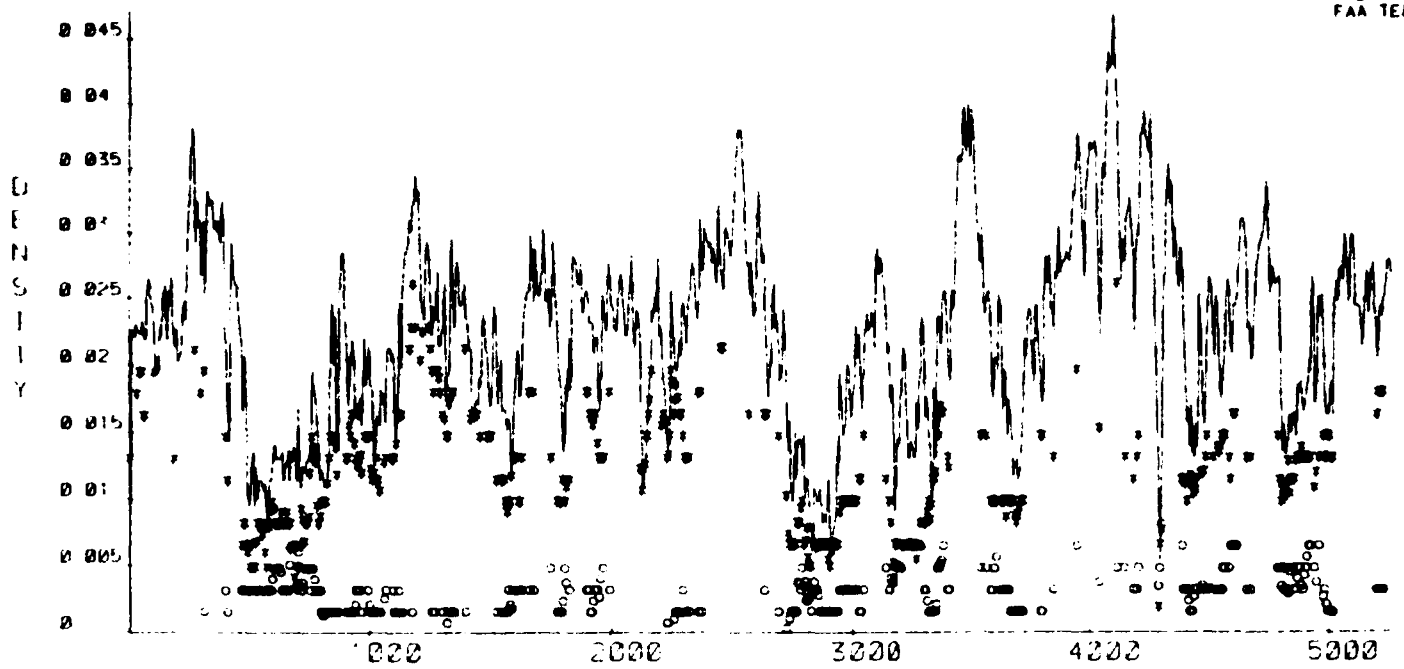

START TIME 10 58 27
STOP TIME 12 26 28

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 92	0 28	0	0	0	0	0
1	0 [illegible]	0	0 29	0	0	0	0
2	0 52	0	0	0 48	0	0	0
3	0 4[illegible]	0	0	0	0 56	0	0
4	0 2[illegible]	0	0	0	0	0 73	0
5	0 [illegible]	0	0	0	0	0	0 6
6	1 00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 9	0 [illegible]	0	0	0	0	0
1	0 67	0	0 33	0	0	0	0
2	0 44	0	0	0 56	0	0	0
3	0 22	0	0	0	0 78	0	0
4	0 18	0	0	0	0	0 83	0
5	0 14	0	0	0	0	0	0 86
6	1 00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME 10 58 27
STOP TIME 12 26 28

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 89%
NON MODE C 84%

PROCESSING DATE, OCT 15, 1984

NOTES

FLIGHT SUMMARY

MISSION 120883B.

Destination: Dallas/Fort Worth (DFW)

Flight Date: December 8, 1983

Mission Type: Approaches (seven completed)

Purpose: National tour demonstration

Departure: DFW 13:41:50

Arrival: DFW 15:08:00

Total Flight Time: 1 hour, 27 minutes, 10 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 21; Mode C = 17, includes 16 TA's and 1 RA; Non-Mode C = 4

Advisories Eliminated by Piedmont Suppression Logic = 11

Valid Advisories = 9; Mode C = 5 Non-Mode C = 3

Total Advisory Display Time: 312 seconds

Total Time Bearing was Invalid: 24 seconds (7.7%)

Problems Observed in Flight:

Type: Engineering; traffic advisories were generated on two targets who were close but were rapidly diverging.

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Mode C	15s	-	14	No	-	-	-	TAU	Yes-1	Departure	1310	4	
2. TA-Mode C	11s	-	5	Yes (1s)	-	-	-	(Divergent Target)	Yes-1	Departure	1350	4	(1)
3. TA-Mode C	17s	-	31	No	-	-	-	TAUR	Yes-1	Departure	1350	4	
4. TA-Mode C	21s	-	2	No	-	-	-	TAURTA	Yes-1	Departure	1331	4	
5. TA-Mode C	13s	-	43	Yes (2s)	-	-	-	TAUR	Yes-1	Departure	1350	4	
6. TA-Mode C	21s	14s	15	Yes (7s)	-	0.15	-	TAURTA	No	Pattern	2850	4	(2)
7. TA-Mode C	5s	20s	36	Yes (1s)	1970 ft	0.58	-325	TAURTA	No	Final	700	2	(3)
8. TA-Mode C	6s	-	8	No	-	-	-	DMOD	Yes-1	Departure	1350	4	
9. TA-Mode C	9s	-	33	No	-	-	-	DMOD	Yes-1	Departure	1350	4	
10. TA-Non-Mode C	24s	25s	5	Yes (5s)	-	0.65	-	TAURTA	No	Pattern	4300	5	
11. TA-Non-Mode C	26s	25s	1	Yes (2s)		0.98	-	TAURTA	No	Pattern	4800	5	
12. TA-Mode C	2s	-	40	Yes (1s)	-	-	-	TAURTA	Yes-1	Approach	1700	4	
13. TA-Mode C	7s	-	27	Yes (2s)	-	-	-	TAURTA	Yes-1	Approach	1600	4	
14. TA-Mode C	4s	143s	12	No	1068 ft	0.34	0.0	DMOD	No	Final	900	4	(4)
15. RA-Climb	20s	15s	25	No	487 ft	See Line 16		TAUR	No	Climbout	1000	4	
16. TA-Mode C	22s	-	25	No	300 ft	0.13	260	TAUR	No	Climbout	1300	4	(5)
17. TA-Mode C	5s	-	5	No	-	-	-	(Divergent Target)	Yes	Pattern	4500	5	(1)

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
18. TA-Mode C	8s	-	27	No	-	-	-	TAURTA	Yes-1	Approach	1300	4	
19. TA-Mode C	19s	-	19	No	-	-	-	TAURTA	Yes-1	Approach	1300	4	
20 TA-Non-Mode C	18s	25s	44	Yes (3s)	-	0.99	-	TAURTA	No	Pattern	4800	5	
21 TA-Mode C	42s	39s	31	No	893 ft	1.17	1100	TAURTA	No	Pattern	2800	5	

Notes:

(1) Logic error. TA on divergent target should be suppressed.

(2) Radar Alt - 2312; causes PL4

(3) Projected VMD is opposite of actual VMD. Logically correct but resultant RA would cross altitudes.

(4) Very slow closing rate encounter. Slow rate explains warning time = 143s.

(5) TA after the RA.

120883B - *Page 2 of 2*

PROTOTYPE TEST FLIGHT 12-8-83

DATA RECORDED
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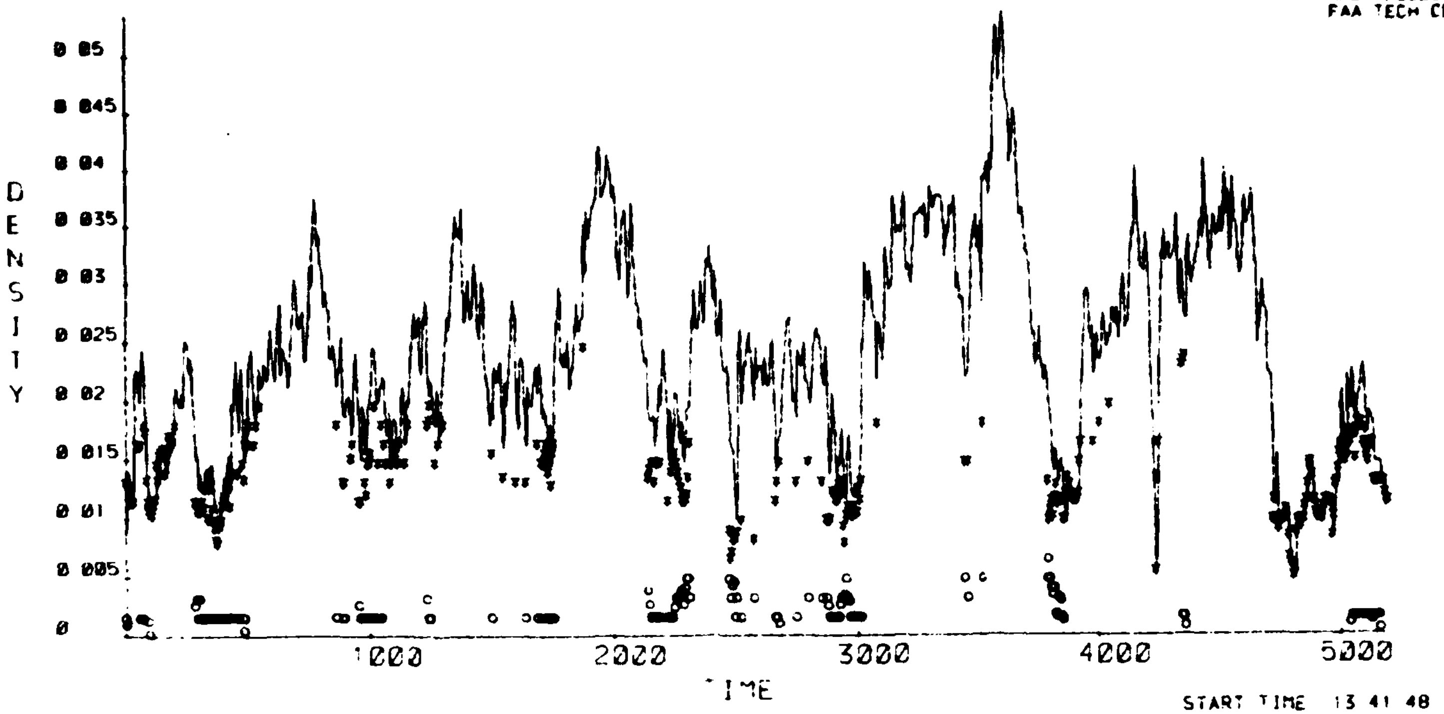


START TIME 13 41 48
STOP TIME. 15 8 30

MODE C MATRIX (PRESENT COAST STATE × FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0 9	0 1	0	0	0	0	0
1	0 7	0	0 3	0	0	0	0
2	0 53	0	0	0 47	0	0	0
3	0 38	0	0	0	0 63	0	0
4	0 29	0	0	0	0	0 7'	0
5	0 23	0	0	0	0	0	0.77
6	1 00	0	0	0	0	0	0

START TIME. 13 41 48
STOP TIME. 15 8 32

NON MODE C MATRIX (PRESENT COAST STATE × FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0 91	0 1	0	0	0	0	0
1	0 65	0	0 34	0	0	0	0
2	0 48	0	0	0 53	0	0	0
3	0 29	0	0	0	0 71	0	0
4	0 03	0	0	0	0	0 97	0
5	0 07	0	0	0	0	0	0 93
6	1 00	0	0	0	0	0	0

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 86%
NON MODE C 85%

PROCESSING DATE. OCT 15.1984

NOTES.

FLIGHT SUMMARY

MISSION 120883C.

Destination: Los Angeles (LAX)

Flight Date: December 8, 1983

Mission Type: En Route Dallas/Fort Worth to LAX

Purpose: National tour

Departure: Dallas/Fort Worth 17:36:00

Arrival: LAX 20:33:15

Total Flight Time: 2 hours, 57 minutes, 15 seconds

TCAS Configuration: Same as mission 101183A.

SUMMARY DATA.

See density plot and transition matricies for surveillance performance.

Total Advisories: 2; Mode C TA = 1, Non-Mode C TA = 1

Advisories Eliminated by Piedmont Suppression Logic = 1

Valid Advisories = 2

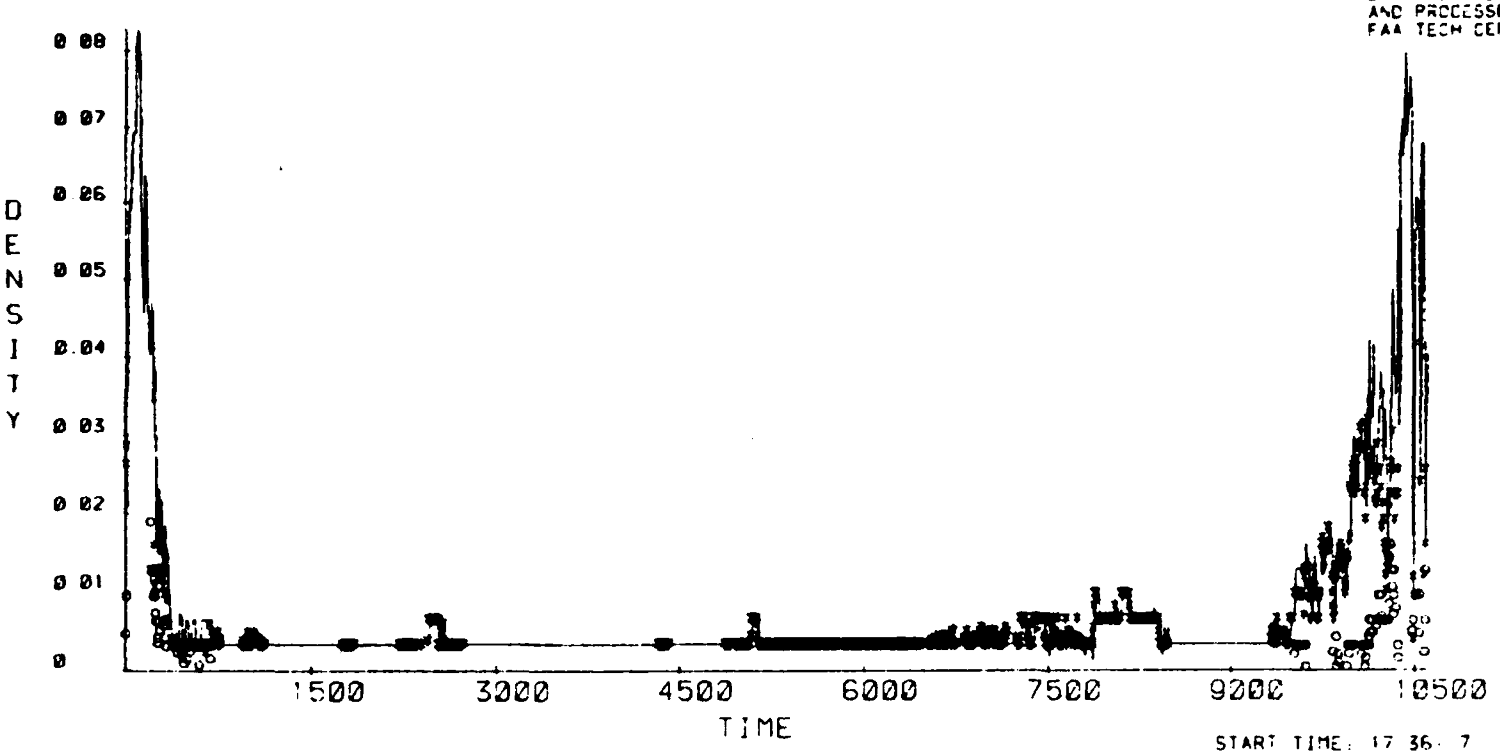
Total Advisory Display Time: 51 seconds

Total Time Bearing was Invalid: 1 second (1.9%)

Problems Observed in Flight: Density overloading caused system resets

PROTOTYPE TEST FLIGHT 12-8-83C

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



START TIME: 17 36: 7
STOP TIME 20 33 8

FUTURE COAST STATE (PRESENT COAST STATE by rows)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.91	0.09	0	0	0	0	0
1	0.68	0	0.32	0	0	0	0
2	0.42	0	0	0.58	0	0	0
3	0.3	0	0	0	0.7	0	0
4	0.24	0	0	0	0	0.76	0
5	0.11	0	0	0	0	0	0.89
6	1.00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.84	0.16	0	0	0	0	0
1	0.59	0	0.41	0	0	0	0
2	0.33	0	0	0.67	0	0	0
3	0.28	0	0	0	0.71	0	0
4	0.14	0	0	0	0	0.86	0
5	0.16	0	0	0	0	0	0.84
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME, 17.36: 7
STOP TIME, 20.33: 8

LEGEND

MODE C	***
NON MODE C	ooo
TOTAL	——

UPDATE RATES

MODE C	86%
NON MODE C	74%

PROCESSING DATE. OCT 30,1984

NOTES

FLIGHT SUMMARY

MISSION 120983/MISSION 121083.

Destination: Los Angeles (LAX)

Flight Date: December 9, 10, 1983

Mission Type: 120983 National tour demonstration flight
121083 National tour - surveillance data gathering mission in Los Angeles Basin

Departure LAX 13:05:04 (120983)
LAX 13:30:10 (121083)

Arrival LAX 14:45:45 (120983)
LAX 15:31:54 (121083)

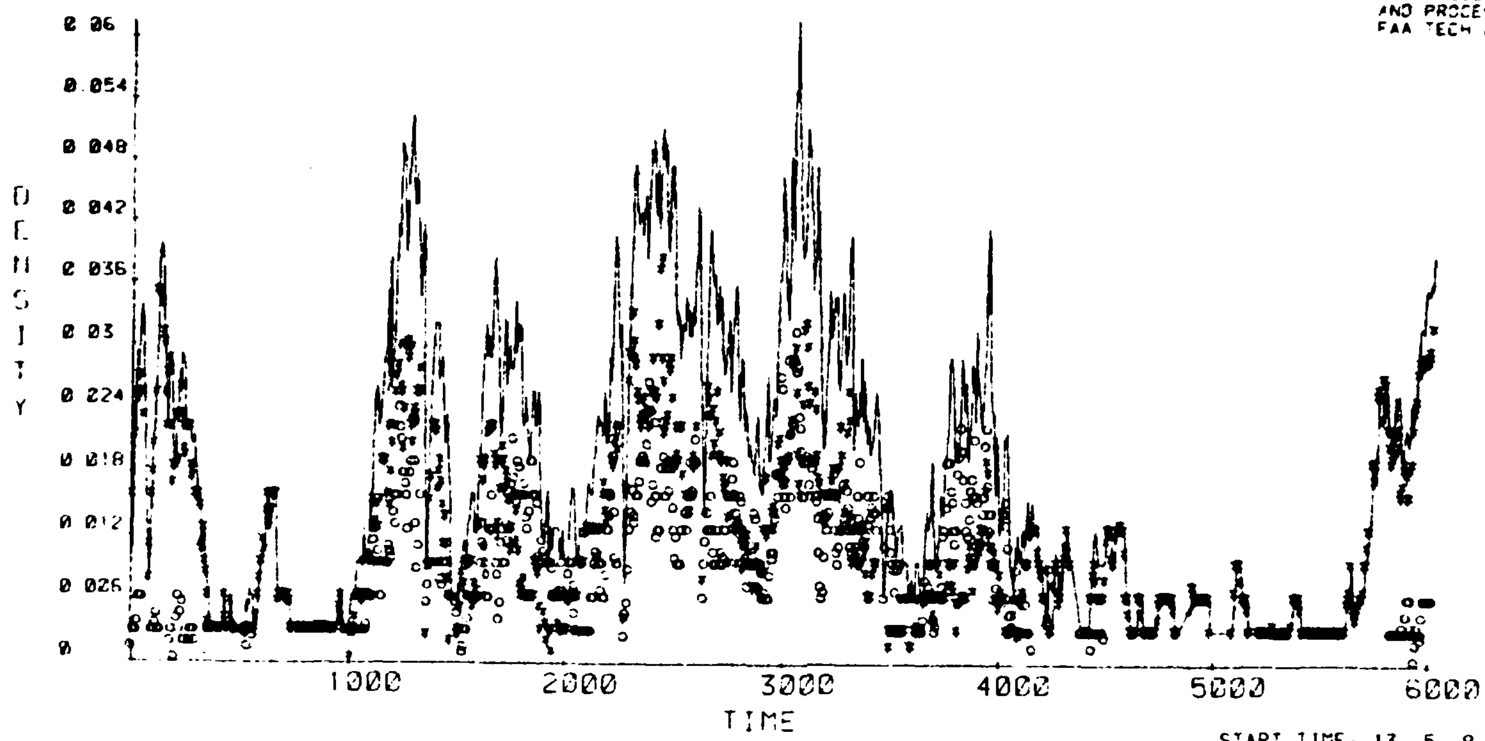
Total Flight Time: 3 hours, 42 minutes, 25 seconds

TCAS Configuration: Same as mission 120883C

Problems Observed in Flight: Density overloading caused system resets

PROTOTYPE TEST FLIGHT 12-9-83

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



START TIME: 13 5 8
STOP TIME 14.45 39

FUTURE COAST STATE (MODE C MATRIX)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.82	0.18	0	0	0	0	0
1	0.63	0	0.37	0	0	0	0
2	0.48	0	0	0.52	0	0	0
3	0.38	0	0	0	0.62	0	0
4	0.22	0	0	0	0	0.78	0
5	0.23	0	0	0	0	0	0.77
6	1.00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE (NON MODE C MATRIX)

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.83	0.17	0	0	0	0	0
1	0.55	0	0.45	0	0	0	0
2	0.36	0	0	0.64	0	0	0
3	0.28	0	0	0	0.72	0	0
4	0.27	0	0	0	0	0.73	0
5	0.14	0	0	0	0	0	0.86
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME 13 5. 8
STOP TIME: 14.45 39

LEGEND

MODE C	***
NON MODE C	ooo
TOTAL	——

UPDATE RATES

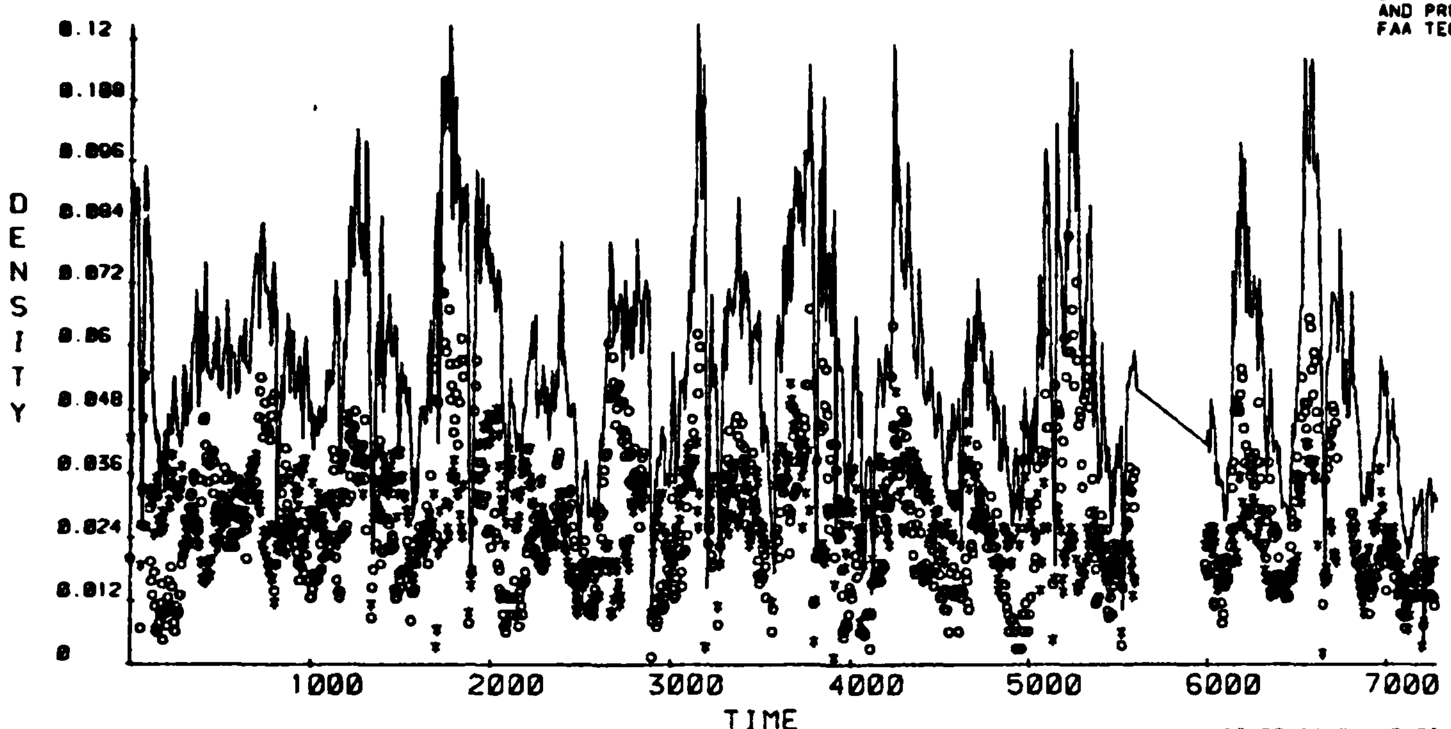
MODE C	75%
NON MODE C	72%

NOTES:

PROCESSING DATE: OCT 30,1984

PROTOTYPE TEST FLIGHT 12-10-83

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



START TIME: 13:30:10
STOP TIME: 15:31:48

MODE C MATRIX

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.8	0.2	0	0	0	0	0
1	0.61	0	0.39	0	0	0	0
2	0.46	0	0	0.54	0	0	0
3	0.31	0	0	0	0.69	0	0
4	0.22	0	0	0	0	0.78	0
5	0.17	0	0	0	0	0	0.83
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.78	0.22	0	0	0	0	0
1	0.52	0	0.48	0	0	0	0
2	0.36	0	0	0.65	0	0	0
3	0.27	0	0	0	0.73	0	0
4	0.21	0	0	0	0	0.79	0
5	0.17	0	0	0	0	0	0.83
6	1.00	0	0	0	0	0	0

START TIME: 13:30:10
STOP TIME: 15:31:48

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 72%
NON MODE C 65%

PROCESSING DATE: OCT 29,1984

NOTES:

FLIGHT SUMMARY

MISSION 121283A.

Destination: Seattle (Boeing Field), SEATAC Airport

Flight Date: December 12, 1983

Mission Type: Approaches (nine completed)

Purpose: TCAS demonstration, national tour

Departure: Boeing Field 10:01:50

Arrival: Boeing Field 12:16:00

Total Flight Time: 2 Hours, 14 Minutes, 10 Seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 23; Mode C = 7, includes 6 TA's and 1 RA; Non-Mode C = 16

Advisories Eliminated by Piedmont Suppression Logic = 0

Valid Advisories = 23

Total Bearing Display Time: 402 seconds

Total Time Bearing was Invalid: 79 seconds (19.7%)

Problems Encountered in Flight: None

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Non-Mode C	16s*	25s	17	No	-	1.94	-	TAURTA	No	En Route	4812	5	
2. TA-Non-Mode C	47s*	25s	26	No	-	1.39	-	TAURTA	No		2850	5	
3. TA-Mode C	4s*	19s	34	No	-	0.86	-	TAURTA	No	Approach	556	2	IOG
4. TA-Mode C	6s	12s	34	No	-	0.57	-	TAURTA	No	Approach	600	2	
5. RA	4s	8s	34	NO	562 ft	0.36	-	TAUR	No	Approach	762	4	IOG
6. TA-Mode C	7s	9s	34	No	818 ft	1.09	-	TAURTA	No	Approach	1218	4	
7. TA-Non-Mode C	11s	21s	1	No	-	1.05	-	TAURTA	No	En Route	4862	5	
8. TA-Mode C	16s	6s	9	Yes (8s)	1268 ft	0.35	-	TAUR	No	Approach	1325	4	
9. TA-Non-Mode C	5s*	25s	29	No	-	1.24	-	TAURTA	No	En Route	4900	5	
10. TA-Non-Mode C	13s	17s	15	Yes (13s)	-	0.80	-	TAURTA	No	En Route	4930	5	
11. TA-Non-Mode C	20s*	19s	27	No	-	1.17	-	TAURTA	No	Approach	1250	4	
12. TA-Non-Mode C	37s*	20s	15	No	-	1.03	-	TAURTA	No	Approach	1137	4	
13. TA-Non-Mode C	27s*	19s	24	Yes (5s)	-	1.23	-	TAURTA	No	Approach	2230	4	
14. TA-Non-Mode C	33s	15s	10	No	-	0.70	-	TAURTA	No	Approach	1931	4	
15. TA-Non-Mode C	24s*	19s	26	Yes (8s)	-	0.66	-	TAURTA	No	Approach	1443	4	
16. TA-Non-Mode C	3s*	22s	26	No	-	0.48	-	TAURTA	No	Approach	1768	4	
17. TA Non-Mode C	14s		12	No	-	0.39	-	-	No	Approach	1831	4	
18. TA-Mode C	1s*	7s	1	No	425 ft	0.35	-	TAURTA	No	Approach	668	2	IOG
19. TA-Mode C	7s	7s	1	No	900 ft	0.64	-	TAURTA	No	Approach	1300	4	
20. TA-Non-Mode C	12s	25s	15	No	-	1.15	-	TAURTA	No	En Route	3737	5	
21. TA-Non-Mode C	50s	25s	27	No	-	1.42	-	TAURTA	No	En Route	4062	5	
22. TA-Non-Mode C	6s	17s	31	Yes (6s)	-	1.05	-	TAURTA	No	En Route	3200	5	
23. TA-Non-Mode C	39s	19s	15	Yes (39s)	-	0.69	-	TAURTA	No	Approach	2118	4	

*

Notes:

IOG denotes intruder on ground

121283A

PROTOTYPE TEST FLIGHT 12-12-83A

DATA RECORDED
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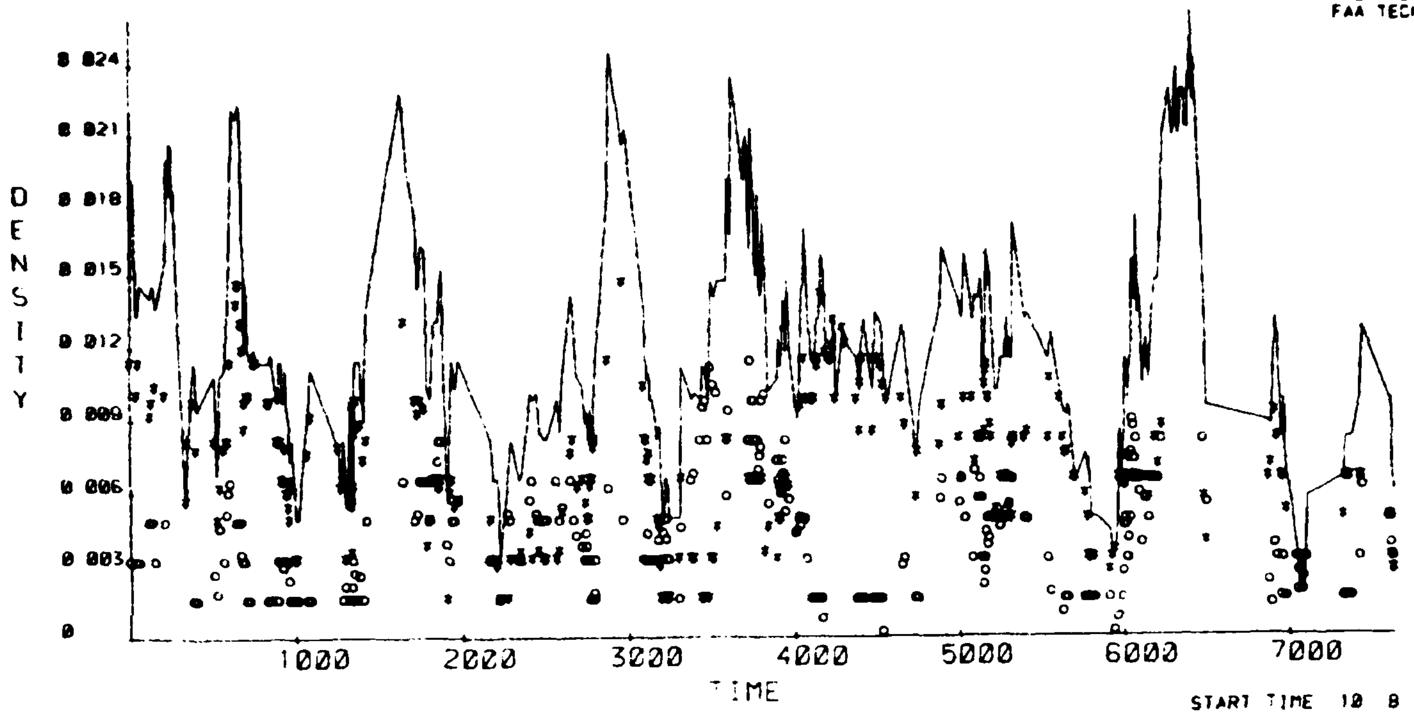

START TIME 10 8 1
STOP TIME 12.15.30

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 93	0 07	0	0	0	0	0
1	0 74	0	0 26	0	0	0	0
2	0 52	0	0	0 48	0	0	0
3	0 32	0	0	0	0 68	0	0
4	0 20	0	0	0	0	0 60	0
5	0 23	0	0	0	0	0	0.77
6	1 00	0	0	2	0	0	2

MODE C MATRIX

START TIME 10 8 1
STOP TIME 12 15.30

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0 92	0 08	0	0	0	0	2
1	0 7	0	0 3	0	0	0	0
2	0.46	0	0	0 54	0	0	0
3	0 32	2	0	0	0 68	0	0
4	0 14	0	0	0	0	0 86	0
5	0 16	0	0	0	0	0	0 84
6	1 00	0	0	2	0	0	2

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 90%
NON MODE C 87%

PROCESSING DATE: OCT 15, 1984

NOTES:

FLIGHT SUMMARY

MISSION 121283B.

Destination: San Francisco (SFO)

Flight Date: December 12, 1983

Mission Type: Typical operation from Seattle to San Francisco

Purpose: National demonstration tour

Departure: Boeing Field 13:32:30

Arrival: SFO 15:06:11

Total Flight Time: 1 hour, 33 minutes, 41 seconds

SUMMARY DATA.

Total Advisories: 6; Mode C = 3, 2 TA's and 1 RA; Non-Mode C = 3

Advisories Eliminated by Piedmont Suppression Logic = 0

Valid Advisories = 6

Total Bearing Display Time: 141 seconds

Total Time Bearing was Invalid: 2 seconds (1.4%)

Problems Encountered in Flight: None

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Range (nmi)	Alts (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Non-Mode C	21s	20s	30	No	-	1.04	-	TAURTA	No	Approach (SFO)	2200	4	
2. TA-Non-Mode C	31s*	18s	7	No	-	0.68	-	TAURTA	No	Approach (SFO)	150	2	
3. TA-Mode C	69s*	39s	30	No	-643 ft	See line 27		TAURTA	No	Approach (SFO)	4625	5	
4. RA Descend	10s	23s	30	No	-300 ft	0.80	-700	TAUR	No	Approach (SFO)	2393	5	
5. TA-Mode C	7s	28s	30	NO	-568 ft	0.79	-700	TAURTA	No	Approach (SFO)	2318	5	
6. TA-Non-Mode C	3s*	11s	6	Yes (2s)	-	0.77	-	TAURTA	No	Approach (SFO)	1993	4	

* Data Loss

121283B

PROTOTYPE TEST FLIGHT 12-12-83B

DATA RECORDED
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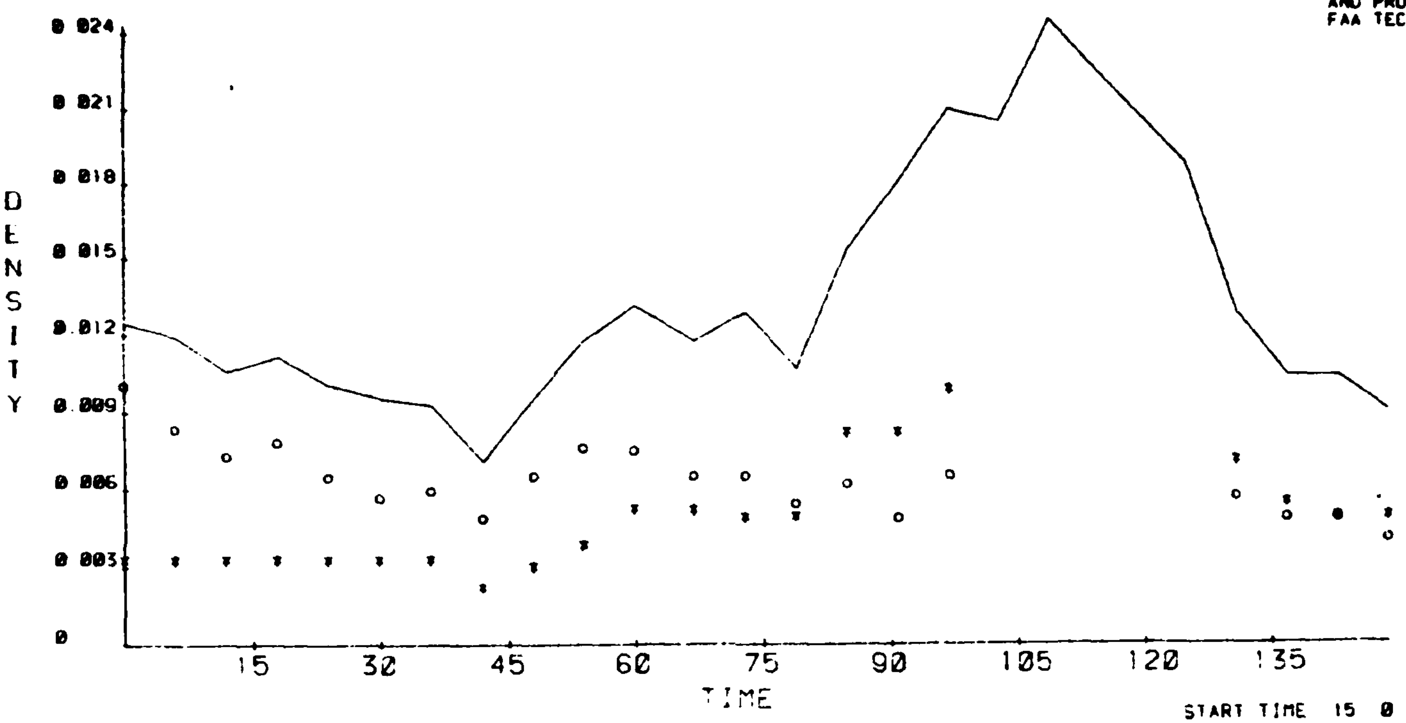

START TIME 15 0.44
STOP TIME: 15 3.13

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.9	0.1	0	0	0	0	0
1	0.72	0	0.28	0	0	0	0
2	0.1	0	0	0.8	0	0	0
3	0.38	0	0	0	0.63	0	0
4	0	0	0	0	0	1.00	0
5	0	0	0	0	0	0	1.00
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME: 15 0.44
STOP TIME: 15 3.13

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.87	0.13	0	0	0	0	0
1	0.69	0	0.31	0	0	0	0
2	0.35	0	0	0.65	0	0	0
3	0.18	0	0	0	0.82	0	0
4	0.11	0	0	0	0	0.89	0
5	0.13	0	0	0	0	0	0.88
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C	***
NON MODE C	ooo
TOTAL	——

UPDATE RATES

MODE C	84%
NON MODE C	80%

PROCESSING DATE: OCT 15, 1984

NOTES:

FLIGHT SUMMARY

MISSION 121383.

Destination: San Francisco International Airport (SFO)

Flight Date: December 13, 1983

Mission Type: Approaches (10 completed)

Purpose: TCAS demonstration national tour

Departure: SFO 10:12:38 (morning) and 14:05:05 (afternoon)

Arrival: SFO 11:19:08 (morning) and 15:40:11 (afternoon)

Total Flight Time: 2 hours, 41 minutes, 36 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 22; Mode C = 18, includes 1 RA and 17 TA's; Non-Mode C = 4

Advisories Eliminated by Piedmont Suppression Logic = 0

Valid Advisories: 22

Total Bearing Display Time: 277 seconds

Total Time Bearing was Invalid: 11 seconds (3.9%)

Problems Encountered in Flight: Ships radar altimeter went inoperative for 3 minutes. During that time, TCAS went to performance level 1.

	Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1.	TA-Mode C	25s*	*	14	Yes (1s)	-	*	*	*	No		-231	2	
2.	TA-Non-Mode C	20s*	20s*	43	No	-	1.01	2118	TAURTA	No		1787	4	
3.	TA-Mode C	2s*	35s*	23	Yes (1s)	-431 ft	*	*	TAURTA	No		2600	5	
4.	TA-Mode C	22s*	39s*	23	No	-700 ft	2.86	606	TAURTA	No		3100	5	
5.	TA-Mode C	6s*	33s*	41	Yes (6s)	-1150 ft	*	*	TAURTA	No		1293	4	Coasted Out
6.	TA-Mode C	17s	19s	4	No	-	0.84	443	TAURTA	No		531	4	
7.	TA-Non-Mode C (Same TA as above)													
8.	TA-Mode C	18s	31s	14	No	-143 ft	0.63	493	TAURTA	No		306	4	
9.	TA-Mode C	15s*	40s*	34	No	-750 ft	3.37	-469	TAURTA	No		3600	5	
10.	TA-Mode C	28s	34.5s	30	No	62 ft	1.39	437	TAURTA	No		968	4	
11.	TA-Non-Mode C	21s*	19s*	5	No	-	0.76	568	TAURTA	No		568	4	
12.	TA-Mode C	16s*	33s*	27	No	762 ft	0.72	837	TAURTA	No		1531	4	
13.	RA	4s	16s	27	No	731 ft	0.72	837	TAUR	No		1531	4	
14.	TA-Mode C	21s	13s	27	No	762 ft	0.72	837	TAURTA	No		1531	4	
15.	TA-Mode C (Same TA as above)													
16.	TA-Mode C (Same TA as above)													
17.	TA-Mode C (Same TA as above)													
18.	TA-Mode C	25s	35s	32	No	-1068 ft	1.85	-1100	TAURTA	No		1431	4	
19.	TA-Mode C	26s	18s	27	No	-900 ft	1.09	-1007	TAURTA	No		4700	5	
20.	TA-Mode C	1s	3s	35	Yes (1s)	-	0.72	-225	TAURTA	No		-468	2	(Radar Alt=0)
21.	TA-Mode C	2s	7s	36	Yes (1s)	-	0.83	-225	TAURTA	No		-468	2	(Radar Alt=0)
22.	TA-Mode C	8s	20s	29	Yes (1s)	-	0.60	-331	TAURTA	No		-456	2	(Radar Alt=0)

*Data Loss - Data not recorded

121383

PROTOTYPE TEST FLIGHT 12-13-83A

DATA RECORDED
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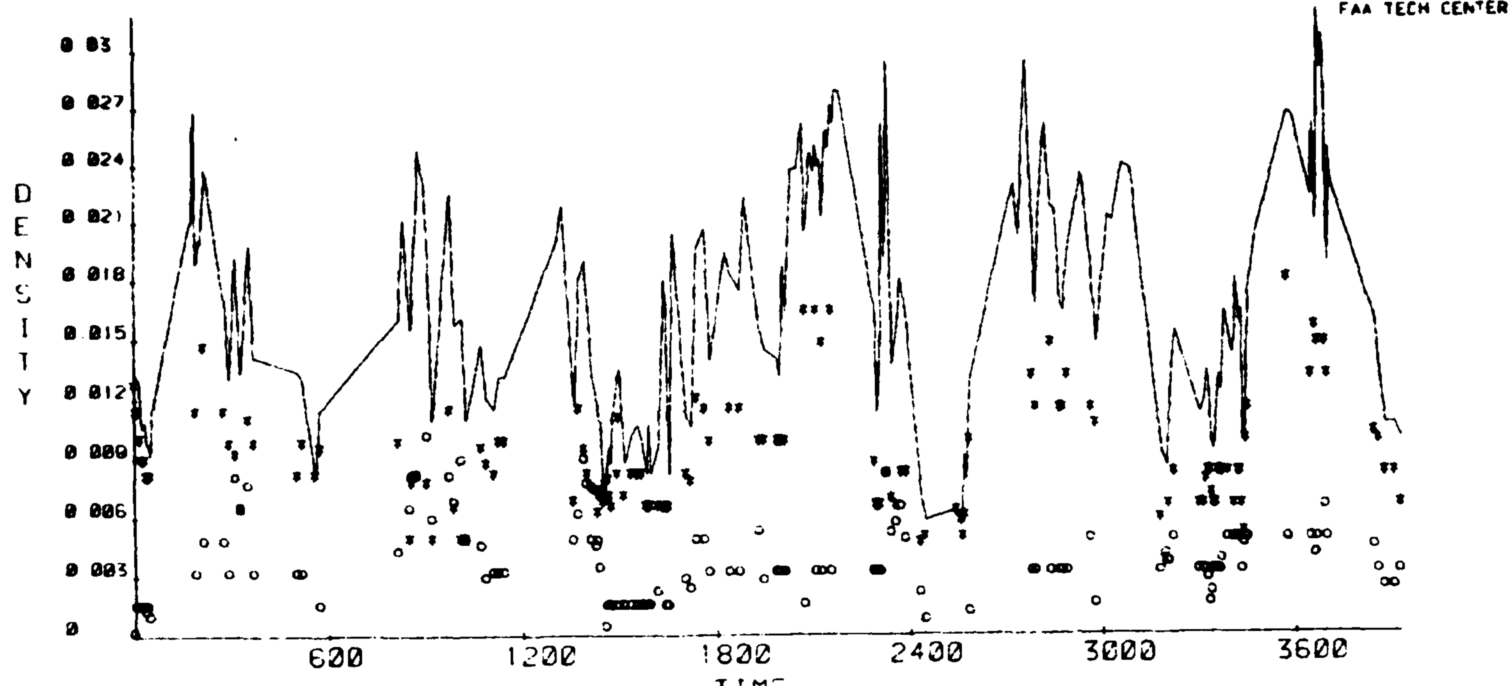


START TIME: 10:12:50
STOP TIME: 11:18:26

MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.93	0.07	0	0	0	0	0
1	0.7	0	0.3	0	0	0	0
2	0.55	0	0	0.45	0	0	0
3	0.37	0	0	0	0.63	0	0
4	0.19	0	0	0	0	0.81	0
5	0.15	0	0	0	0	0	0.85
6	1.00	0	0	0	0	0	0

START TIME: 10:12:50
STOP TIME: 11:18:26

NON MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.91	0.09	0	0	0	0	0
1	0.71	0	0.29	0	0	0	0
2	0.65	0	0	0.35	0	0	0
3	0.17	0	0	0	0.83	0	0
4	0.27	0	0	0	0	0.73	0
5	0	0	0	0	0	0	1.00
6	1.00	0	0	0	0	0	0

LEGEND

MODE C ***
NON MODE C ooo
TOTAL —

UPDATE RATES

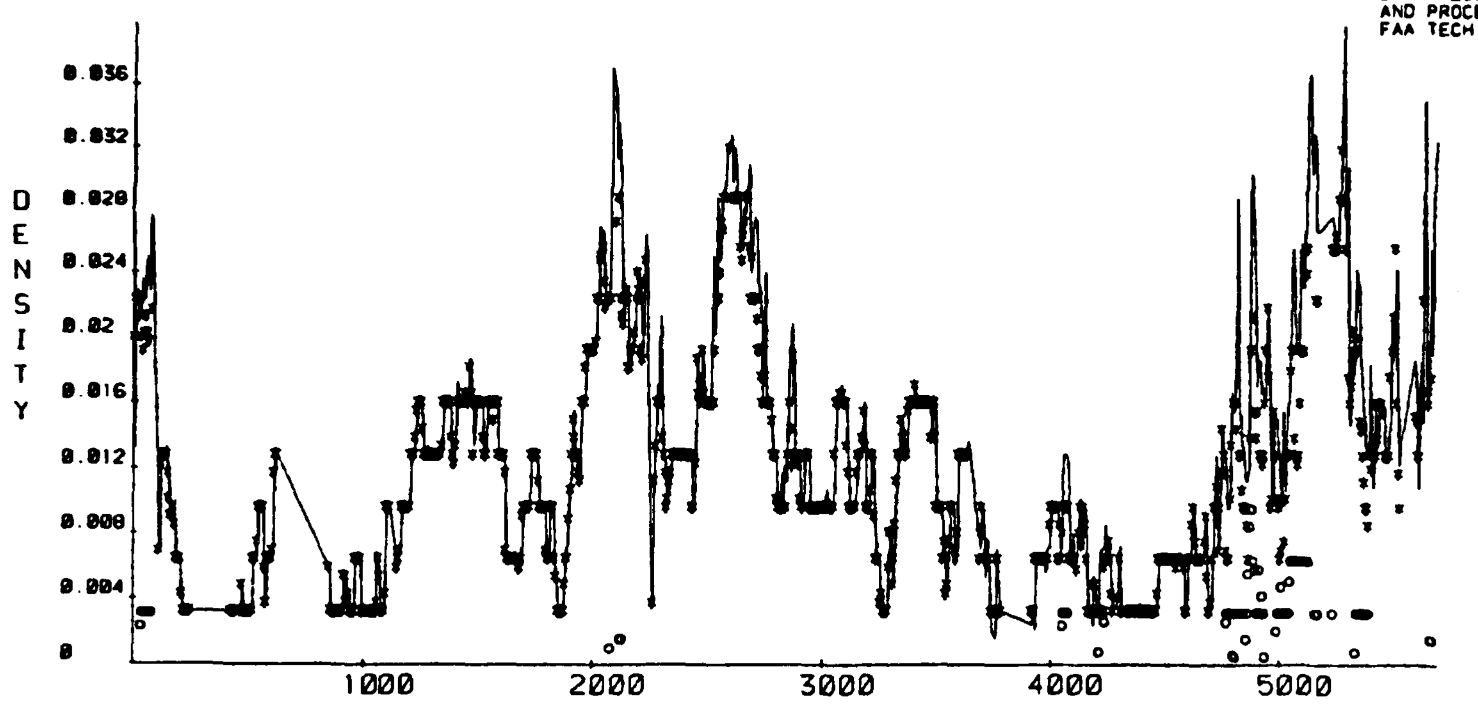
MODE C 90%
NON MODE C 88%

PROCESSING DATE: OCT 15, 1984

NOTES:

PROTOTYPE TEST FLIGHT 12-13-83B

DATA RECORDED AND PROCESSED BY FAA TECH CENTER



START TIME: 14: 6:40
STOP TIME: 15:41:36

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.87	0.13	0	0	0	0	0
1	0.69	0	0.31	0	0	0	0
2	0.52	0	0	0.48	0	0	0
3	0.41	0	0	0	0.6	0	0
4	0.22	0	0	0	0	0.78	0
5	0.16	0	0	0	0	0	0.84
6	1.00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.86	0.14	0	0	0	0	0
1	0.57	0	0.43	0	0	0	0
2	0.37	0	0	0.63	0	0	0
3	0.23	0	0	0	0.77	0	0
4	0.18	0	0	0	0	0.82	0
5	0.07	0	0	0	0	0	0.93
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME: 14: 6:40
STOP TIME: 15:41:36

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ———

UPDATE RATES

MODE C 82%
NON MODE C 76%

PROCESSING DATE: OCT 30,1984

NOTES:

FLIGHT SUMMARY

MISSION 121483.

Destination: FAA Technical Center (ACY)

Flight Date: December 14, 1983

Mission Type: En Route, coast to coast

Purpose: TCAS demonstration, national tour

Departure: San Francisco (SFO) 12:14:20

Arrival: ACY 17:00:26

Total Flight Time: 4 hours, 46 minutes, 6 seconds

TCAS Configuration: Same as mission 101183A

SUMMARY DATA.

Total Advisories: 2, Non-Mode C

Advisories Eliminated by Piedmont Suppression logic = 0

Valid Advisories: 2

Total Bearing Display Time: 37 seconds

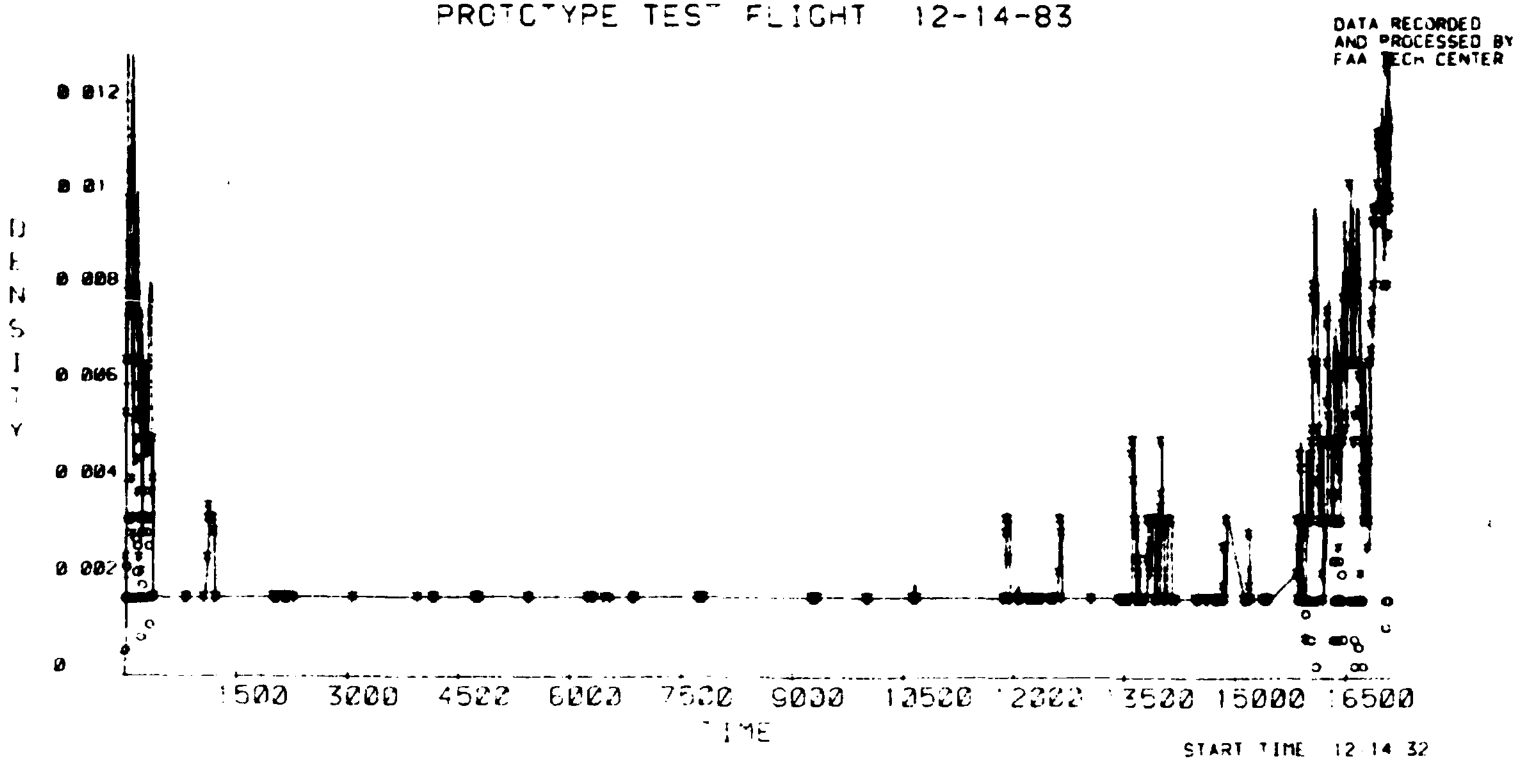
Total Time Bearing was Invalid: 20 seconds (54%)

Problems Observed in Flight: None

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. Non-Mode C	29s	30s	43	Yes (13s)	-	2.4		TAURTA	No	ACY Approach	15000	6	
2. Non-Mode C	8s	29s	36	Yes (7s)	-	3.1		TAURTA	No	ACY Approach	11300	6	

121483

PROTOTYPE TEST FLIGHT 12-14-83



START TIME 12 14 32
STOP TIME 16 59 57

MODE C MATRIX

PRESENT COAST STATE	FUTURE COAST STATE 0	1	2	3	4	5	6
0	0 91	0 09	0	0	0	0	0
1	0 65	0	0 35	0	0	0	0
2	0 39	0	0	0 61	0	0	0
3	0 25	0	0	0	0 75	0	0
4	0 16	0	0	0	0	0 84	0
5	0 09	0	0	0	0	0	0 91
6	1 00	0	0	0	0	0	0

START TIME 12 14 32
STOP TIME 16 59 57

NON MODE C MATRIX

PRESENT COAST STATE	FUTURE COAST STATE 0	1	2	3	4	5	6
0	0 83	0 17	0	0	0	0	0
1	0 52	0	0 48	0	0	0	0
2	0 4	0	0	0 6	0	0	0
3	0 27	0	0	0	0 73	0	0
4	0 09	0	0	0	0	0 91	0
5	0 2	0	0	0	0	0	0 8
6	1 00	0	0	0	0	0	0

LEGEND

MODE C ###
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 85%
NON MODE C 72%

PROCESSING DATE OCT 15.1984

NOTES

FLIGHT SUMMARY

MISSION 010684.

Destination: MIT Lincoln Lab, Bedford, MA

Flight Date: January 6, 1984

Mission Type: Surveillance/Antenna analysis

Purpose: Verify latest change in antenna SN05

Departure: Technical Center (ACY) 10:47:20

Arrival: Bedford, MA 11:37:45

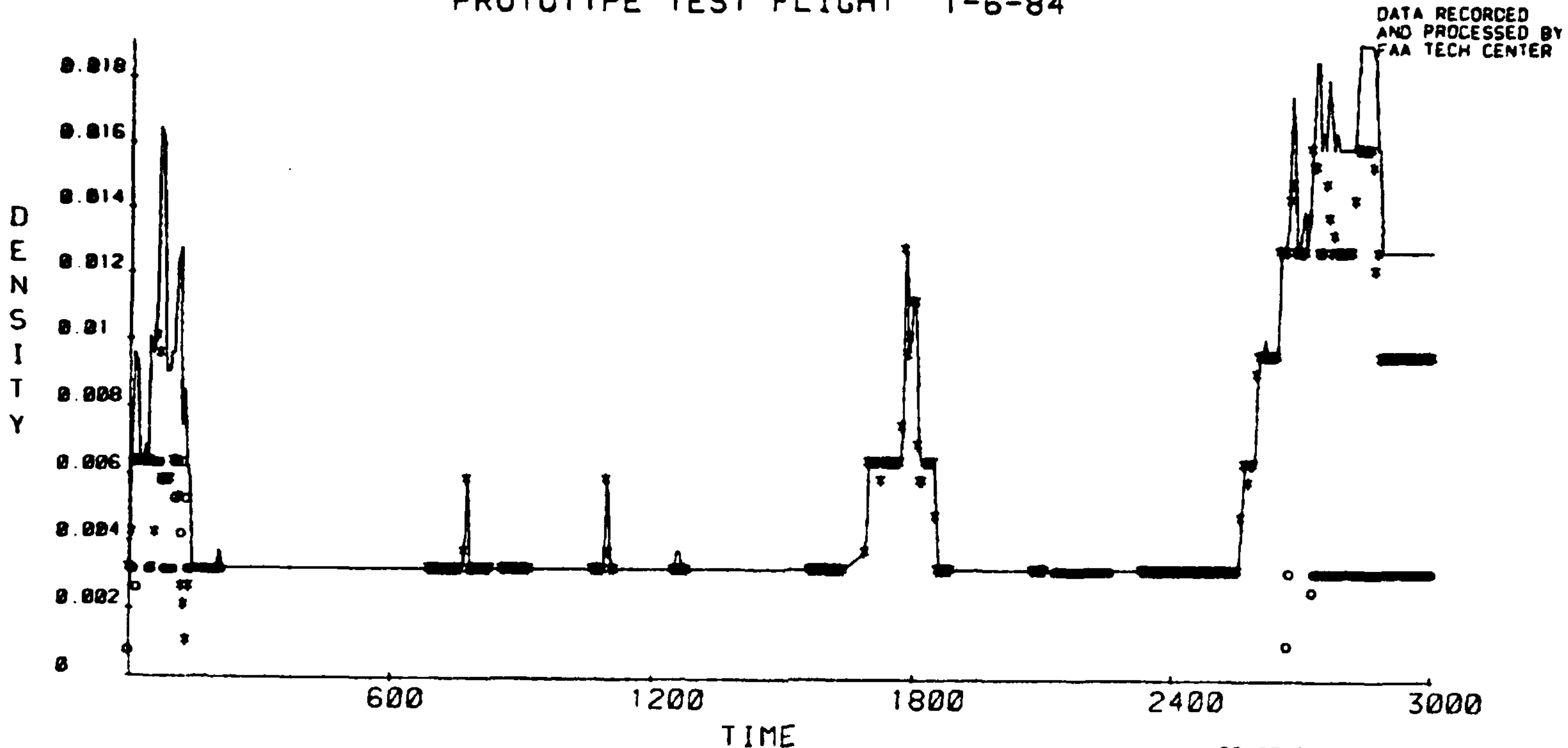
Total Flight Time: 0 hours, 50 minutes, 25 seconds

TCAS Configuration: Same as 120883C

SUMMARY DATA.

See density plot and transition matricies for surveillance performance.

PROTOTYPE TEST FLIGHT 1-6-84



START TIME: 10:47:29
STOP TIME: 11:37:38

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.9	0.1	0	0	0	0	0
1	0.68	0	0.32	0	0	0	0
2	0.42	0	0	0.58	0	0	0
3	0.22	0	0	0	0.78	0	0
4	0.36	0	0	0	0	0.64	0
5	0.22	0	0	0	0	0	0.78
6	1.00	0	0	0	0	0	0

MODE C MATRIX

FUTURE COAST STATE

PRESENT COAST STATE	0	1	2	3	4	5	6
0	0.92	0.08	0	0	0	0	0
1	0.59	0	0.41	0	0	0	0
2	0.37	0	0	0.63	0	0	0
3	0.08	0	0	0	0.92	0	0
4	0.18	0	0	0	0	0.82	0
5	0.11	0	0	0	0	0	0.89
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

START TIME. 10:47:29
STOP TIME. 11:37:38

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

UPDATE RATES

MODE C 85%
NON MODE C 84%

NOTES.

PROCESSING DATE. OCT 29,1984

"LIGHT SUMMARY

MISSION 022184.

Destination: Jacksonville, FL (JAX)

Flight Date: February 21, 1984

Mission Type: Typical operation from ACY-JAX

Purpose: Antenna test

Departure: Technical Center (ACY) 09:06:20

Arrival: JAX 11:15:00

Total Flight Time: 3 hours, 52 minutes, 9 seconds

TCAS Configuration: Piedmont configuration with new intruder on-ground suppression threshold = 1350 feet. IVSI arrows changed to green.

SUMMARY DATA.

Total Advisories: 1 (Result of a logic error)

Advisories Eliminated by Logic Correction: 1

Valid Advisories: 0

Total Bearing Display Time: 10 seconds

Total Time Bearing was Invalid: 0 seconds (0%)

Problems Observed in Flight:

Type: Engineering; incorrect handling of threat test; altitude test of Mode C intruder not invoked when in performance level 2. This problem was also observed in Op Eval flight of 11/30/84 over Newark (EWR). Dalmo Victor implemented a logic correction which was tested 3/84.

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range Alt (nmi) (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Mode C	10s	-	20	No	0 ft	- 4900	TAURTA	See Note	Approach	440	2	(1)

Note:

(1) Incorrect advisory due to logic error.

022184

PROTOTYPE TEST FLIGHT 2-21-84A

DATA RECORDED
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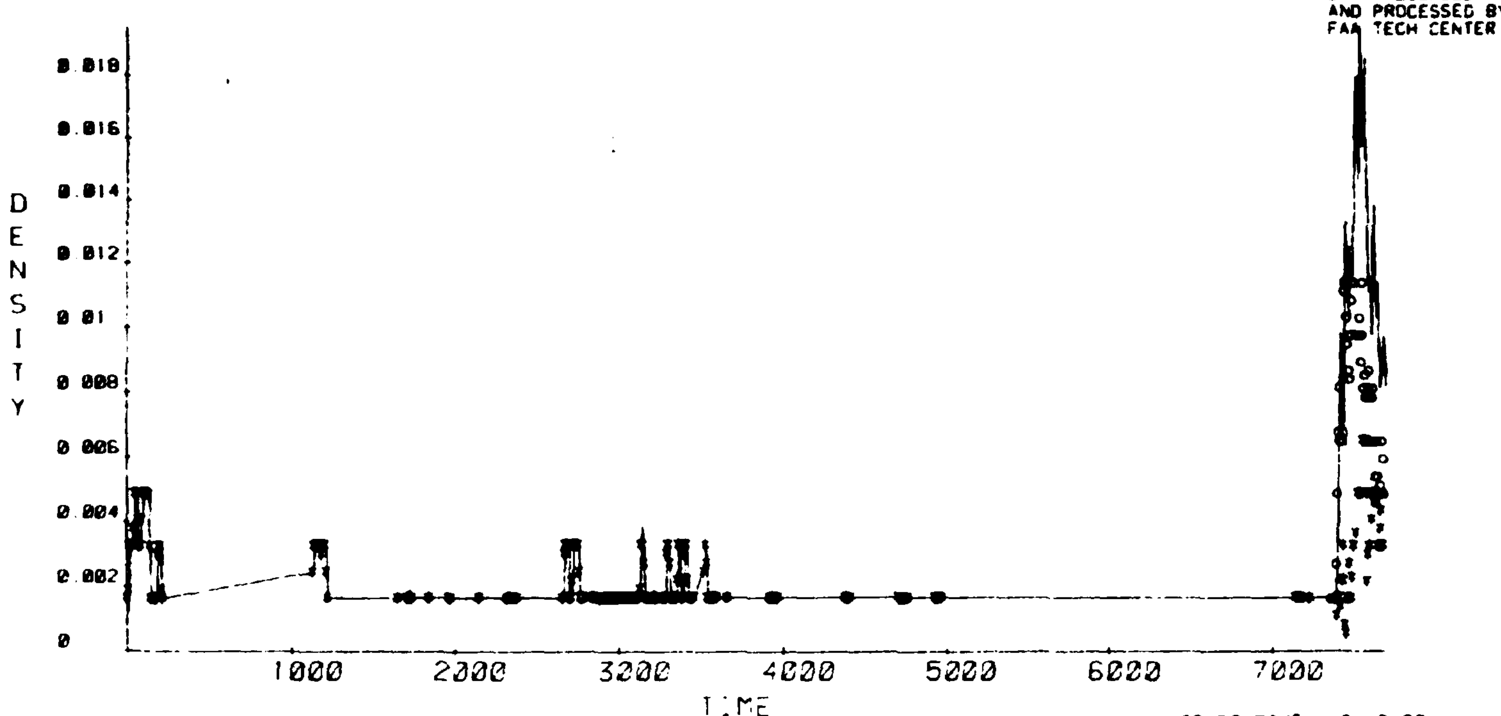


START TIME: 9: 6 20
STOP TIME: 11:14 47

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.88	0.12	0	0	0	0	0
1	0.6	0	0.41	0	0	0	0
2	0.39	0	0	0.61	0	0	0
3	0.31	0	0	0	0.69	0	0
4	0.14	0	0	0	0	0.86	0
5	0.17	0	0	0	0	0	0.83
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME: 9: 6.20
STOP TIME: 11:14 47

PRESENT COAST STATE \ FUTURE COAST STATE	0	1	2	3	4	5	6
0	0.87	0.13	0	0	0	0	0
1	0.71	0	0.29	0	0	0	0
2	0.45	0	0	0.55	0	0	0
3	0.46	0	0	0	0.54	0	0
4	0.21	0	0	0	0	0.79	0
5	0.27	0	0	0	0	0	0.73
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C ***
NON MODE C ooo
TOTAL ——

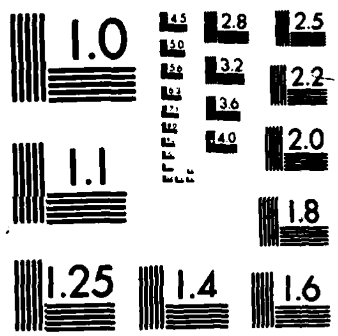
UPDATE RATES

MODE C 88%
NON MODE C 83%

NOTES

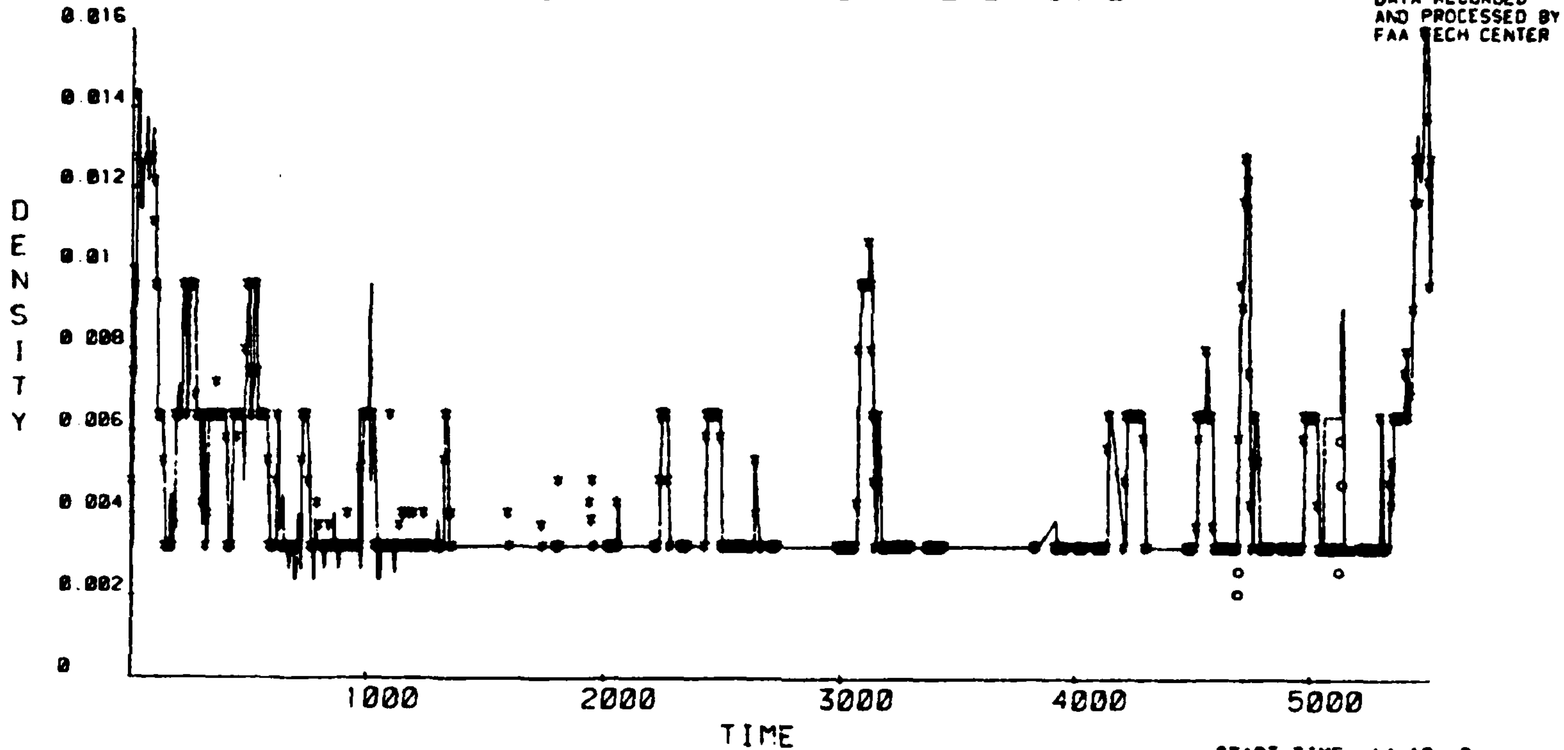
PROCESSING DATE: OCT 15, 1984

AD-A172 260 COMPREHENSIVE TEST AND EVALUATION OF THE DALMO VICTOR 3/3
TCAS (TRAFFIC ALERT.. (U) FEDERAL AVIATION
ADMINISTRATION TECHNICAL CENTER ATLANTIC CIT..
UNCLASSIFIED A J REHMAN FEB 86 DOT/FAA/CT-86/2 F/G 1/2 NL


1.0
4.5
2.8
2.5
5.0
3.2
5.6
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

PROTOTYPE TEST FLIGHT 2/21/84-B

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



START TIME: 14:18: 2
STOP TIME: 15.49.59

MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.91	0.09	0	0	0	0	0
1	0.7	0	0.31	0	0	0	0
2	0.44	0	0	0.56	0	0	0
3	0.3	0	0	0	0.7	0	0
4	0.25	0	0	0	0	0.75	0
5	0.14	0	0	0	0	0	0.86
6	1.00	0	0	0	0	0	0

MODE C MATRIX

START TIME: 14:18: 2
STOP TIME: 15:49:59

NON MODE C MATRIX (rows: PRESENT COAST STATE; columns: FUTURE COAST STATE)

	0	1	2	3	4	5	6
0	0.81	0.19	0	0	0	0	0
1	0.67	0	0.33	0	0	0	0
2	0.33	0	0	0.67	0	0	0
3	0	0	0	0	1.00	0	0
4	0	0	0	0	0	1.00	0
5	0	0	0	0	0	0	1.00
6	1.00	0	0	0	0	0	0

NON MODE C MATRIX

LEGEND

MODE C	***
NON MODE C	ooo
TOTAL	——

UPDATE RATES

MODE C	87%
NON MODE C	70%

NOTES:

PROCESSING DATE: APRIL 4, 1985

FLIGHT SUMMARY

MISSION 031484.

Destination: Washington, DC

Flight Date: March 14, 1984

Mission Type: Approaches (at Norfolk, VA) - 4 completed

Purpose: TCAS demonstration

Departure: Technical Center (ACY) 08:53:00

Arrival: ACY 12:53:40

Total Flight Time: 3 hours, 5 minutes, 40 seconds (includes two stops)

TCAS Configuration: Same as mission 022184

SUMMARY DATA.

Total Advisories: 8; Mode C = 6 TA's, Non-Mode C = 2

Advisories Eliminated by Piedmont Suppression Logic = 0

Valid Advisories: 8

Total Bearing Display Time: 156 seconds

Total Time Bearing was Invalid: 1 second (0.64%)

Problems Encountered in Flight: None

Advisory Type	Duration	Warning Time	Track ID	Bad Bearing	Projected Miss (VMD)	Actual Miss Range (nmi)	Actual Miss Alt (ft)	Advisory Driven by	Advisory Inhibit	Phase of Flight	TCAS Alt	Performance Level	Notes
1. TA-Mode C	39s	45s	41	No	387 ft	3.29	175	TAURTA	No	En Route TCA-DCA	9700	6	
2. TA-Mode C	15s	32s	29	No	1068 ft	0.34	1660	TAURTA	No	DCA Approach	4700	5	
3. TA-Mode C	1s	-	16	No	-	-	-	TAURTA	See Note	Landing	100	2	(1)
4. TA-Mode C	3s	-	42	No	-	-	-	TAURTA	See Note	Takeoff	300	2	(1)
5. TA-Non-Mode C	26s	25s	31	Yes (1s)	-	0.5	-	TAURTA	No	En Route to Richmond, VA	3180	5	
6. TA-Non-Mode C	14s	20s	11	No	-	0.57	-	TAURTA	No	Approach	550	4	
7. TA-Mode C	36s	35s	2	No	100 ft	1.1	100	TAURTA	No	Approach	1700	4	
8. TA-Mode C	22s	31s	2	No	68 ft	1.3		TAURTA	No	Approach	2600	4	

Note

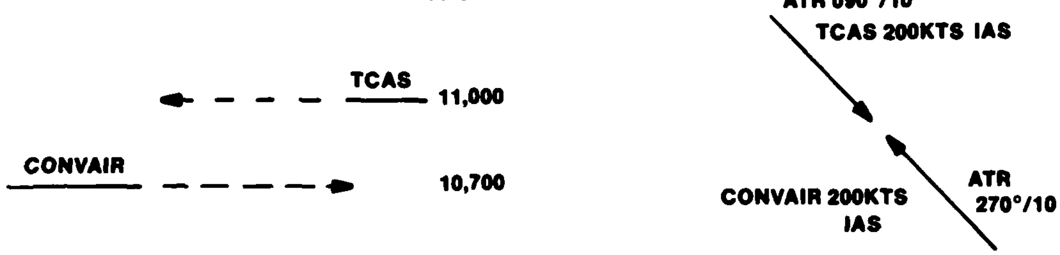
(1) Intruder's altitude error of 100 feet foiled on-ground detection.

031484

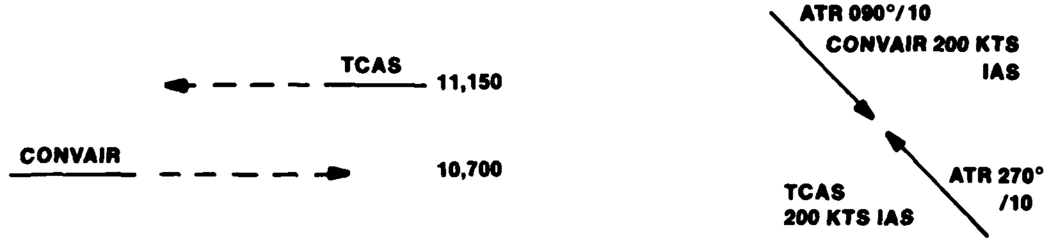
APPENDIX C

ENCOUNTER PROFILES

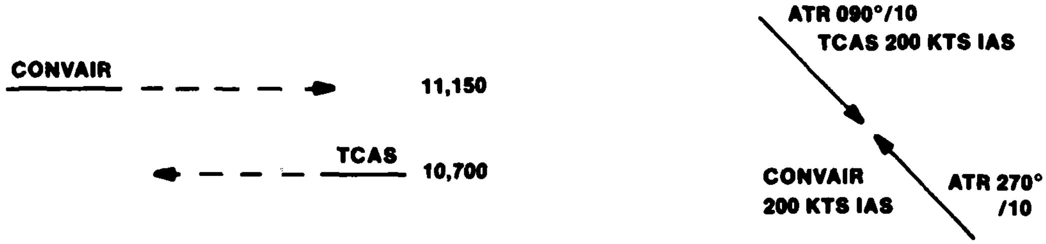
ENGINEERING EVALUATION
PAGE 1 OF 6



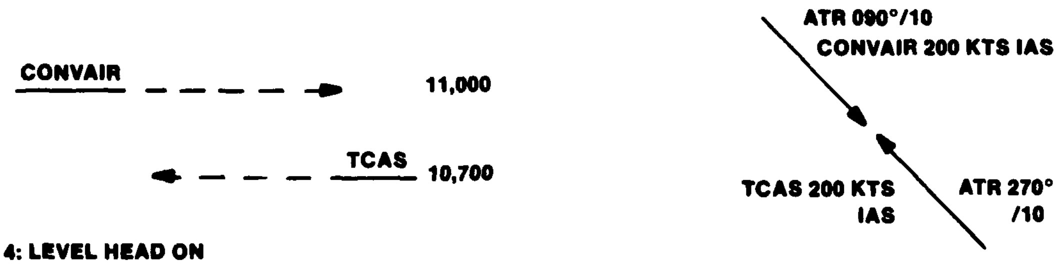
PROFILE 1: LEVEL HEAD ON



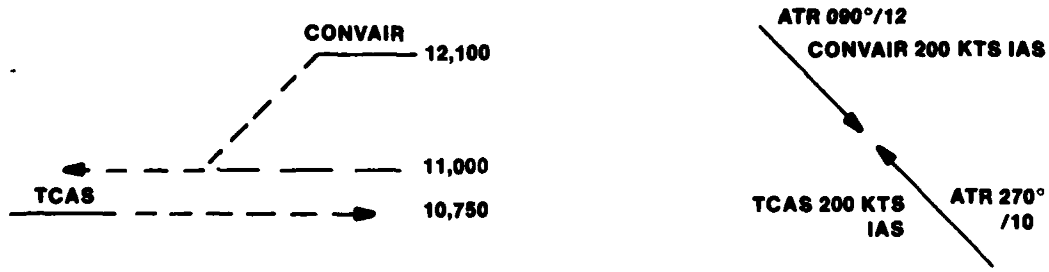
PROFILE 2: LEVEL HEAD ON



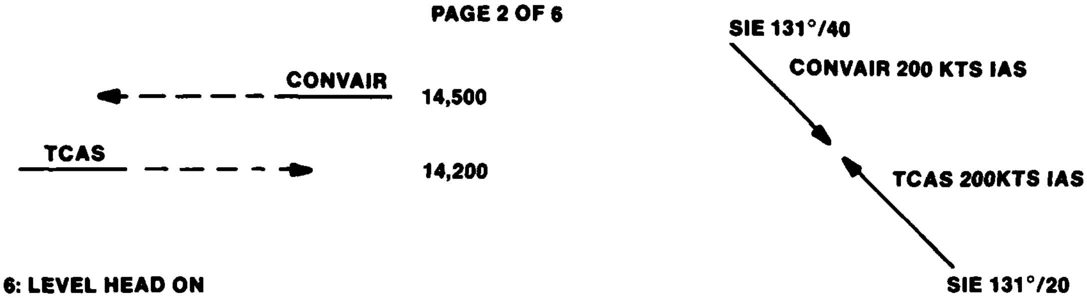
PROFILE 3: LEVEL HEAD ON



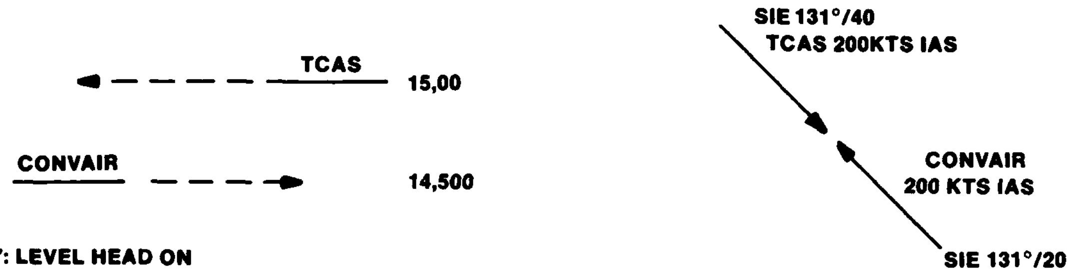
PROFILE 4: LEVEL HEAD ON



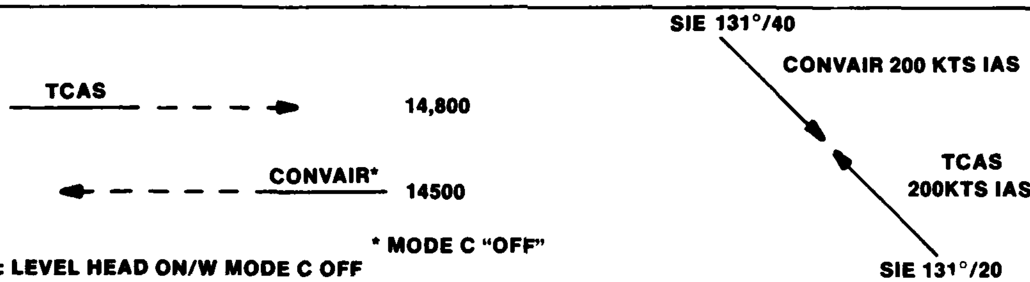
PROFILE 5: INTRUDER MANEUVERING



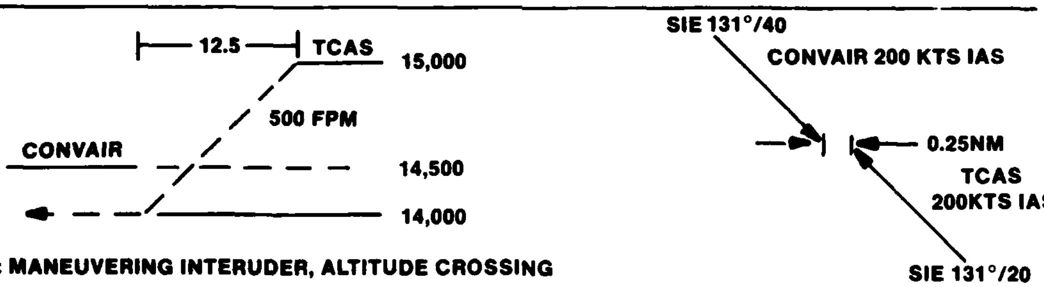
PROFILE 6: LEVEL HEAD ON



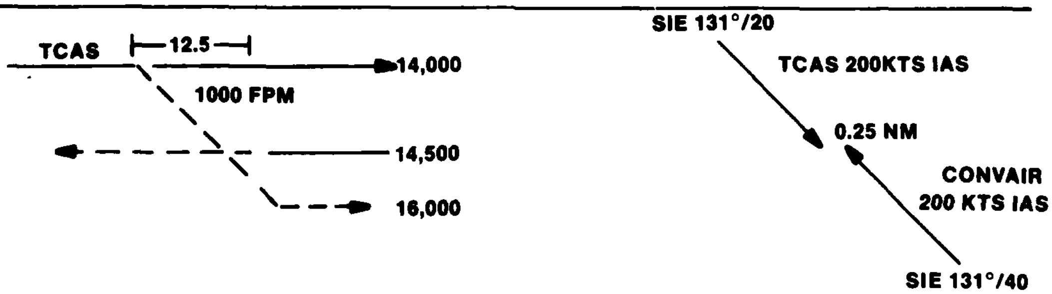
PROFILE 7: LEVEL HEAD ON



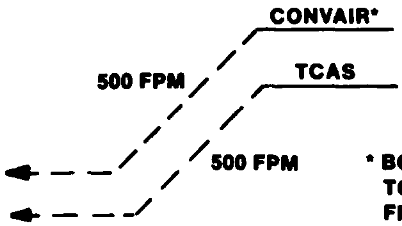
PROFILE 8: LEVEL HEAD ON/W MODE C OFF



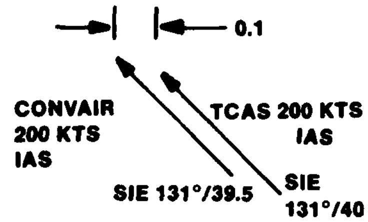
PROFILE 9: MANEUVERING INTERUDER, ALTITUDE CROSSING



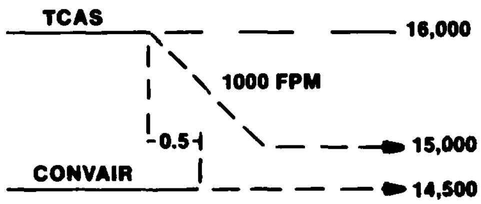
PROFILE 10: MANEUVERING INTRUDER, ALTITUDE CROSSING

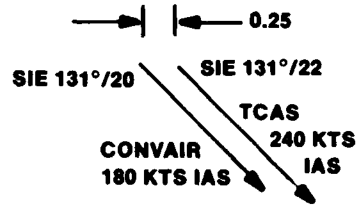


* BOTH AC DESCEND TOGETHER ON COMMAND FROM N-40

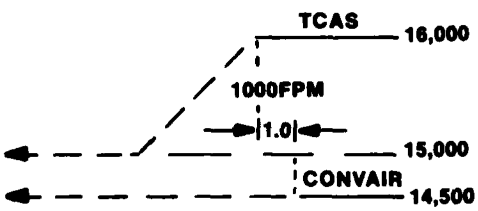


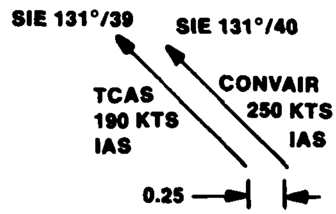
PROFILE 11: ALTITUDE TRACKER TEST



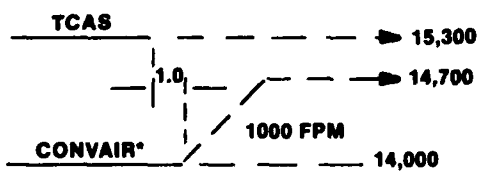


PROFILE 12: TAIL CHASE; RANGE AND ALTITUDE TAU TEST

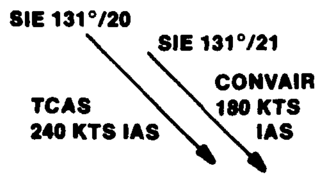




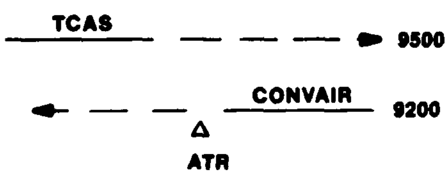
PROFILE 13: TAIL CHASE; CRITICAL INTERVAL TEST

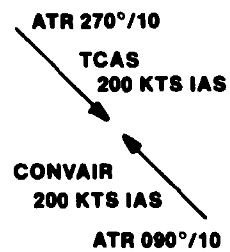


* MODE C "OFF"



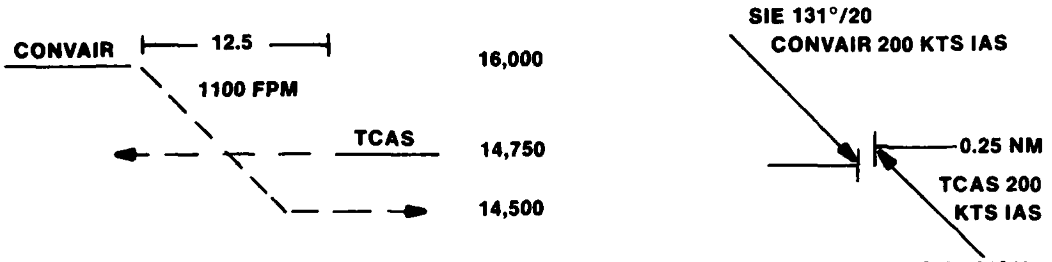
PROFILE 14: TAIL CHASE; NON MODE C RANGE & BEARING JITTER TEST



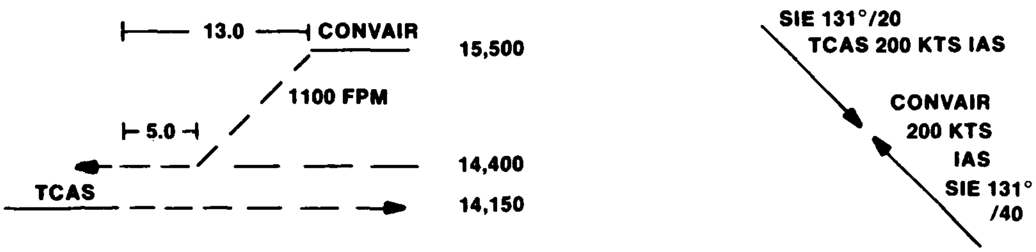


PROFILE 15: LEVEL HEAD ON; PERFORMANCE LEVEL 5

ENGINEERING EVALUATION

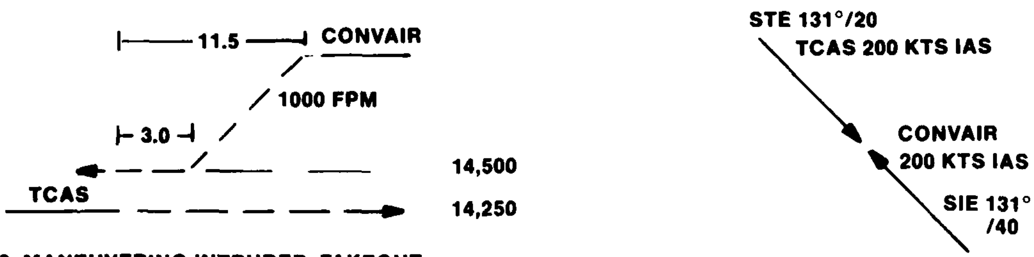


PROFILE 16: MANEUVERING INTRUDER; ALTITUDE CROSSING

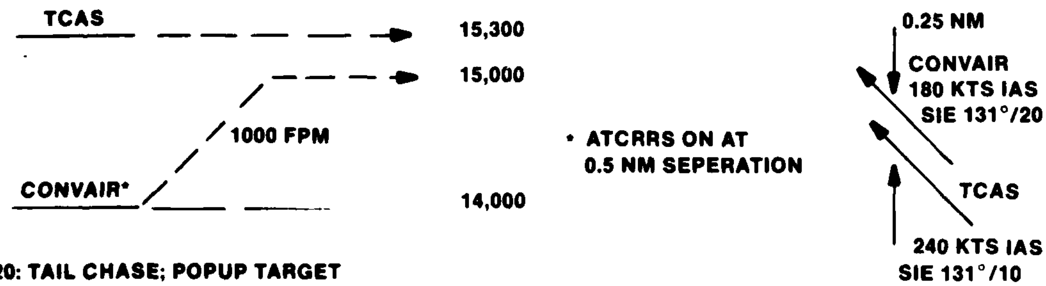


PROFILE 17: MANEUVERING INTRUDER; FIRMNESS TEST

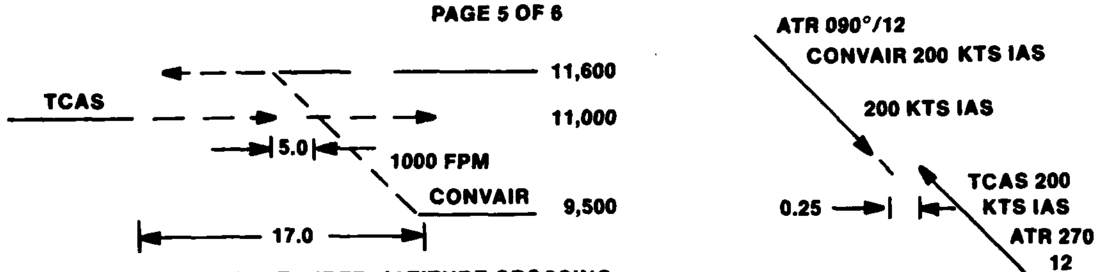
PROFILE 18: MANEUVERING INTRUDER; FIRMNESS TEST



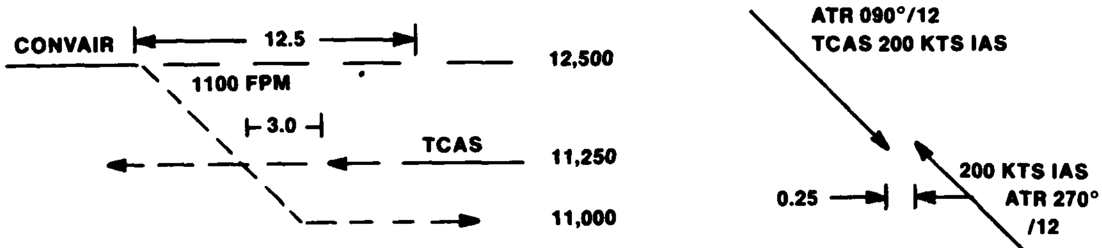
PROFILE 19: MANEUVERING INTRUDER; FAKEOUT



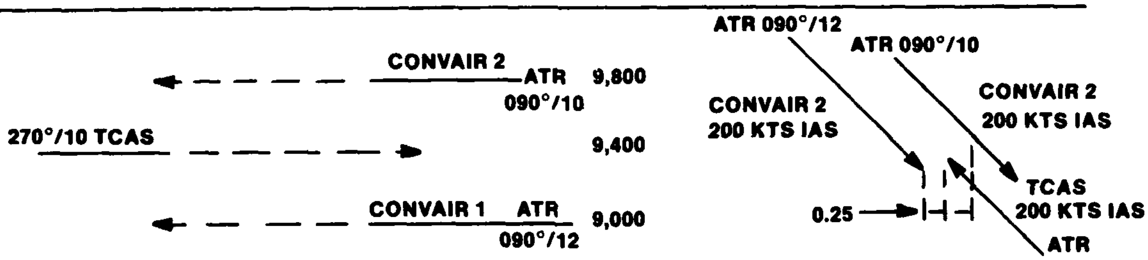
PROFILE 20: TAIL CHASE; POPUP TARGET



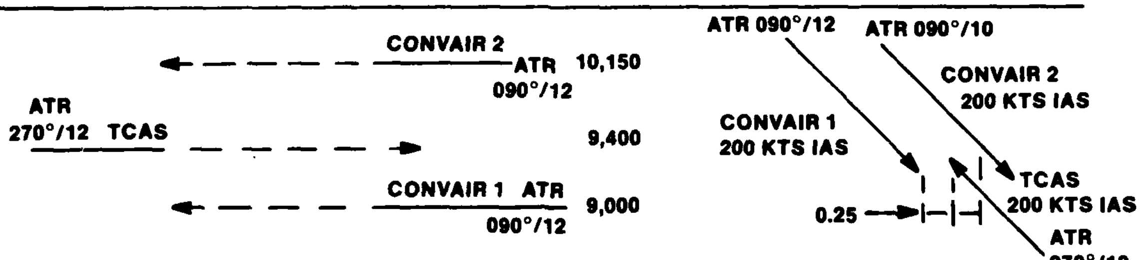
PROFILE 21 MANEUVERING INTRUDER; ALTITUDE CROSSING



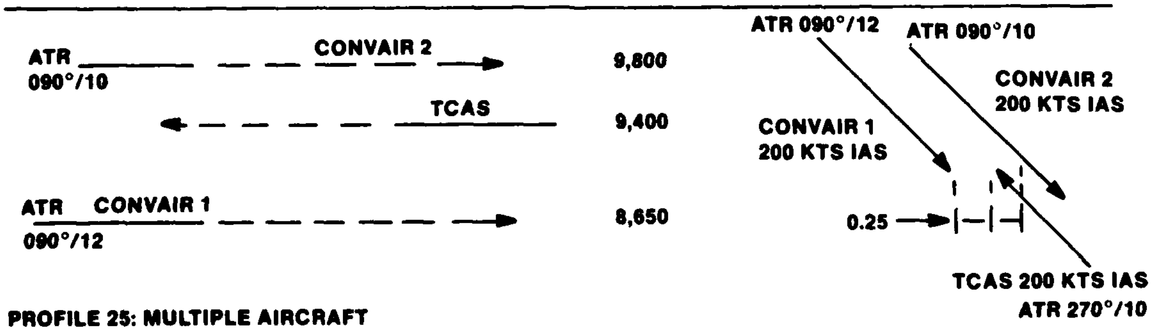
PROFILE 22: MANEUVERING INTRUDER; ALTITUDE CROSSING



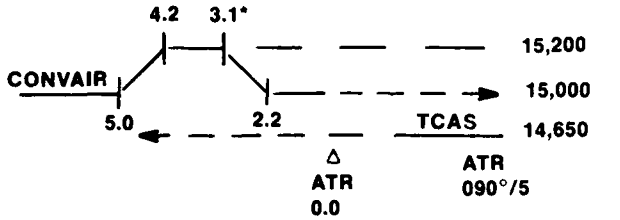
PROFILE 23: MULTIPLE AIRCRAFT

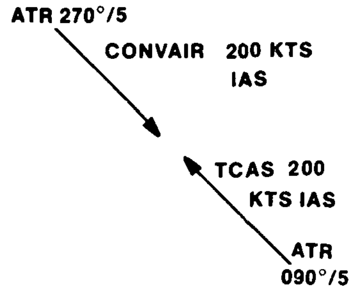


PROFILE 24: MULTIPLE AIRCRAFT



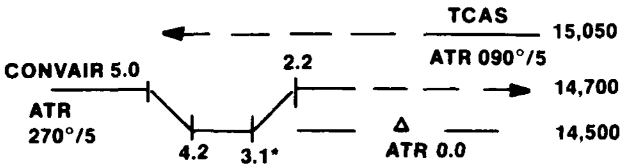
PROFILE 25: MULTIPLE AIRCRAFT

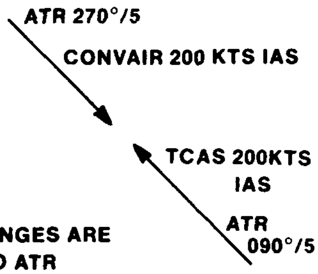




PROFILE 26: ADVISORY SELECTION DESPITE LOW FIRMNESS

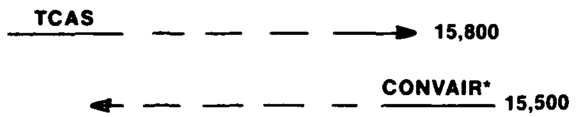
*ALL RANGES ARE DME TO ATR

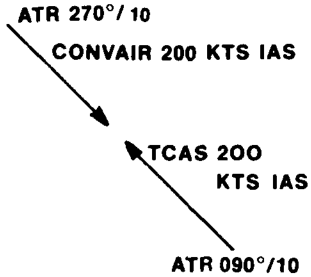




PROFILE 27: ADVISORY SELECTION DESPITE LOW FIRMNESS

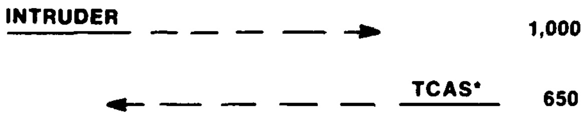
*ALL RANGES ARE DME TO ATR

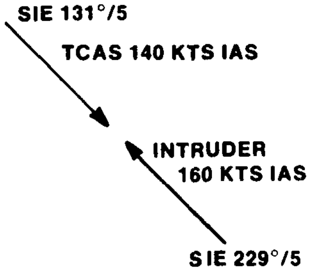




PROFILE 28: ADVISORY INHIBIT; NON MODE C ABOVE 15,500' MSL

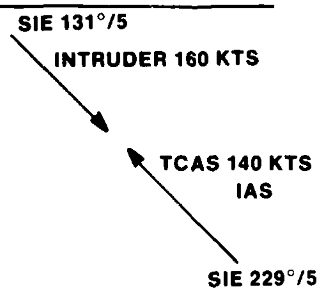
*MODE C "OFF"





PROFILE 29: ADVISORY INHABIT; INHIBIT DESCEND BELOW 700' AGL

*GEAR DOWN
FLAPS 30°,
RADAR ALT < 700'

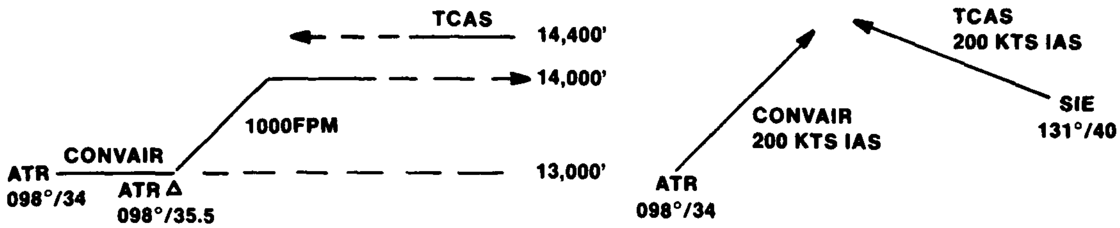


PROFILE 30: ADVISORY INHIBIT INHIBIT CLIMB WHEN "DIRTY"

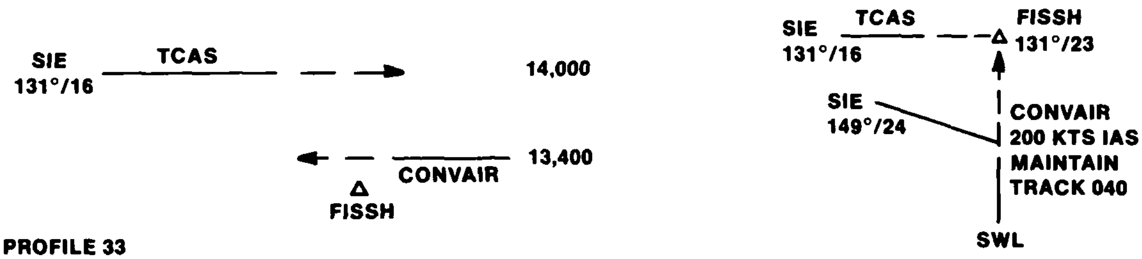
*GEAR DOWN
FLAPS 30°

OPERATIONAL EVALUATION
PAGE 1 OF 2

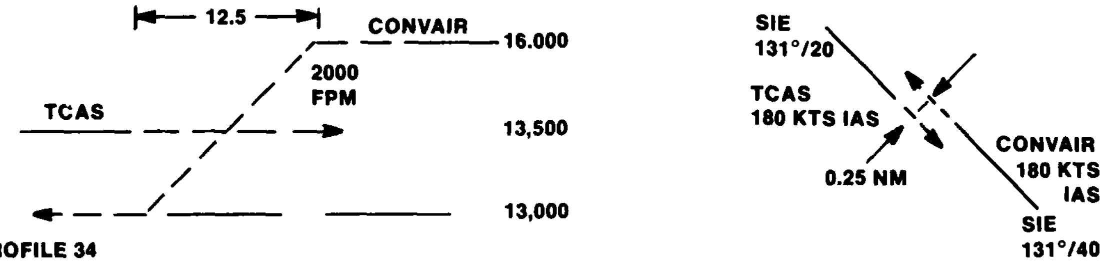
PROFILE 31



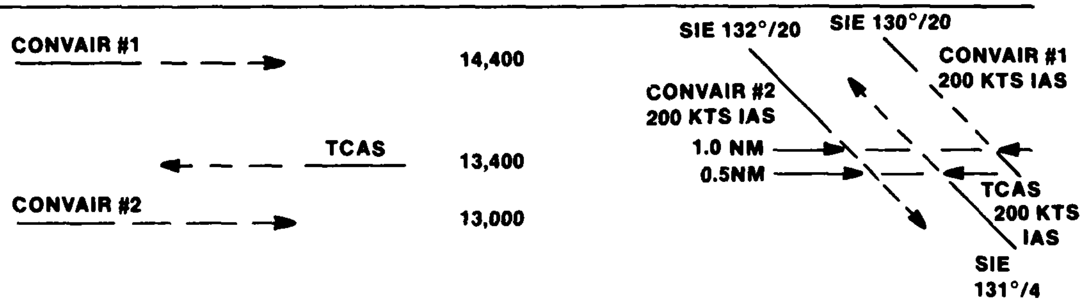
PROFILE 32



PROFILE 33

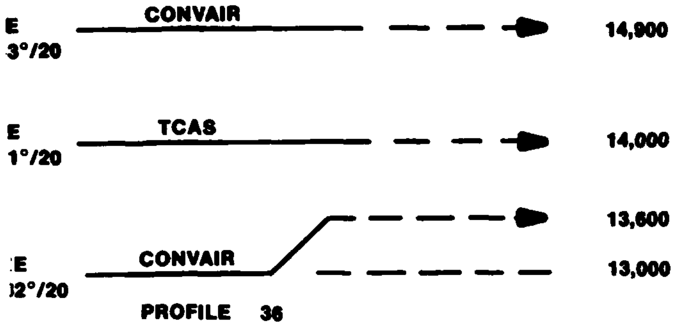


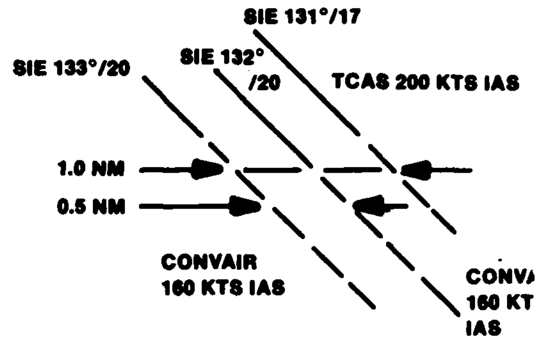
PROFILE 34

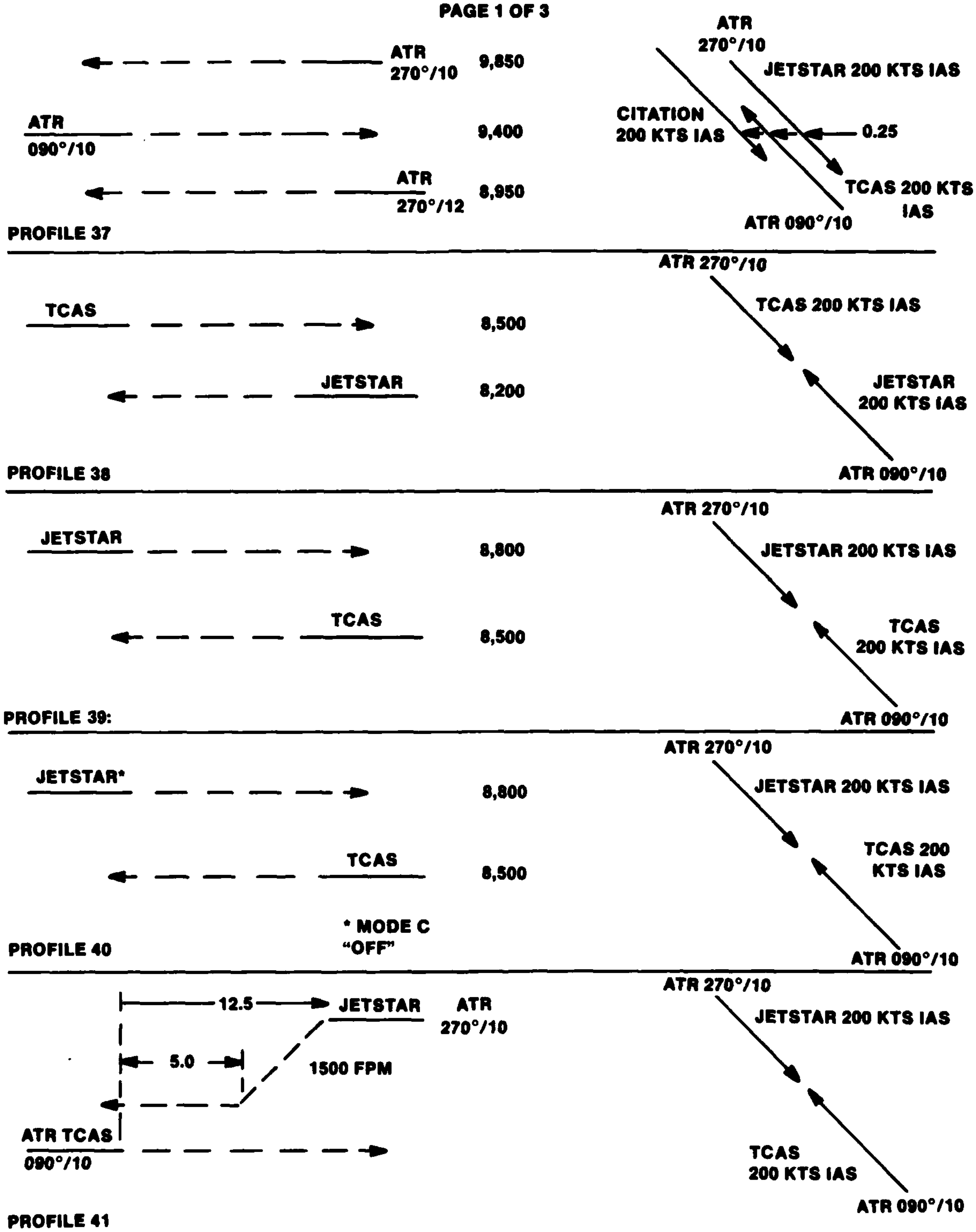


PROFILE 35

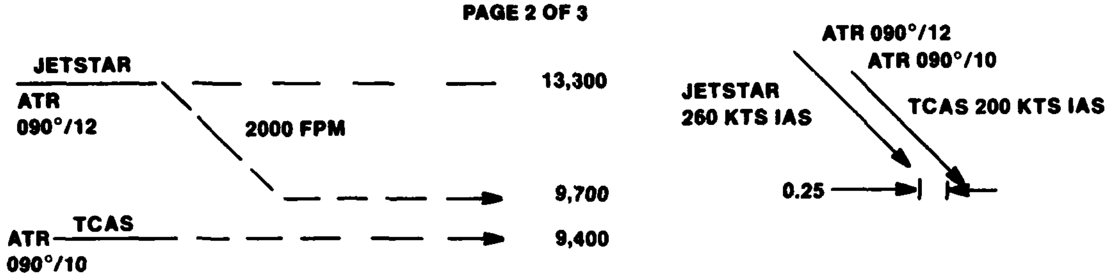
OPERATIONAL EVALUATION
PAGE 2 OF 2



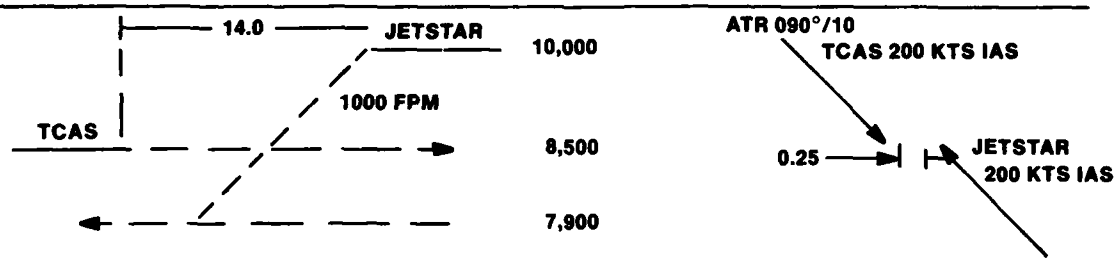



ATR
270°/10
9,850
ATR
090°/10
9,400
ATR
270°/12
8,950
ATR
270°/10
JETSTAR 200 KTS IAS
CITATION
200 KTS IAS
0.25
TCAS 200 KTS
IAS
ATR 090°/10
PROFILE 37
TCAS
8,500
JETSTAR
8,200
ATR 270°/10
TCAS 200 KTS IAS
JETSTAR
200 KTS IAS
ATR 090°/10
PROFILE 38
JETSTAR
8,800
TCAS
8,500
ATR 270°/10
JETSTAR 200 KTS IAS
TCAS
200 KTS IAS
ATR 090°/10
PROFILE 39:
JETSTAR*
8,800
TCAS
8,500
* MODE C
"OFF"
ATR 270°/10
JETSTAR 200 KTS IAS
TCAS 200
KTS IAS
ATR 090°/10
PROFILE 40
12.5
JETSTAR
ATR
270°/10
5.0
1500 FPM
ATR TCAS
090°/10
ATR 270°/10
JETSTAR 200 KTS IAS
TCAS
200 KTS IAS
ATR 090°/10
PROFILE 41

CERTIFICATION
PAGE 2 OF 3

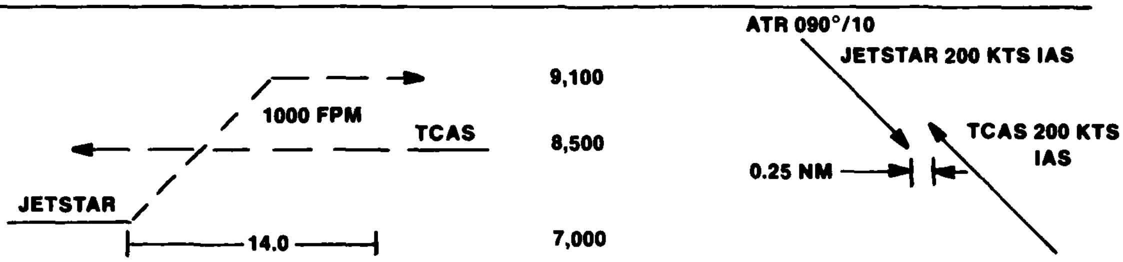


PROFILE 42



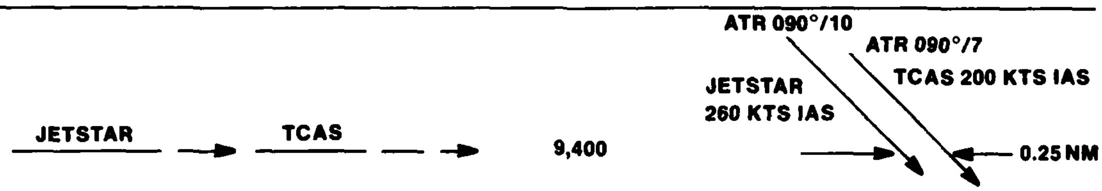
PROFILE 43

ATR 270°/10

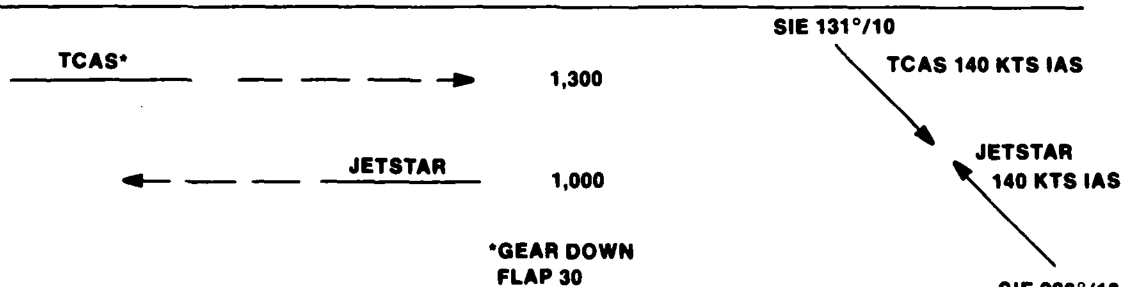


PROFILE 44

ATR 270°/10



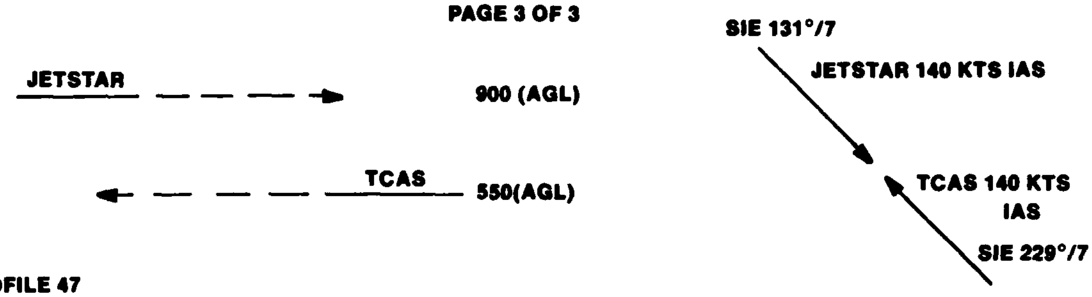
PROFILE 45



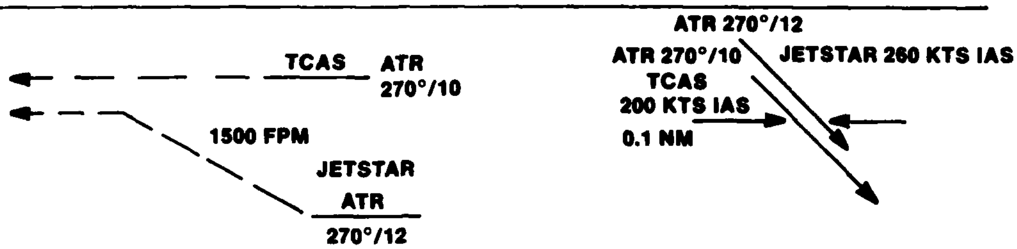
*GEAR DOWN
FLAP 30

PROFILE 46

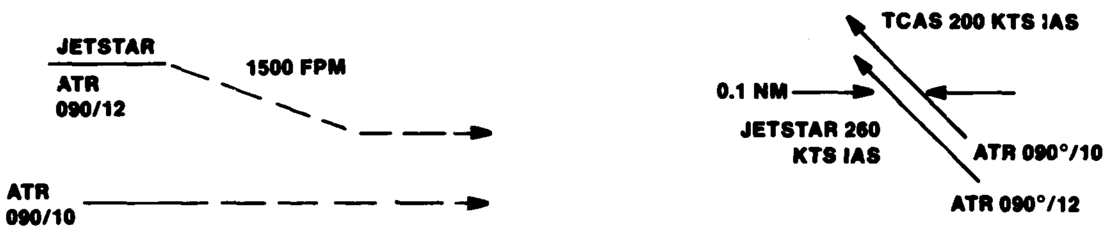
CERTIFICATION
PAGE 3 OF 3



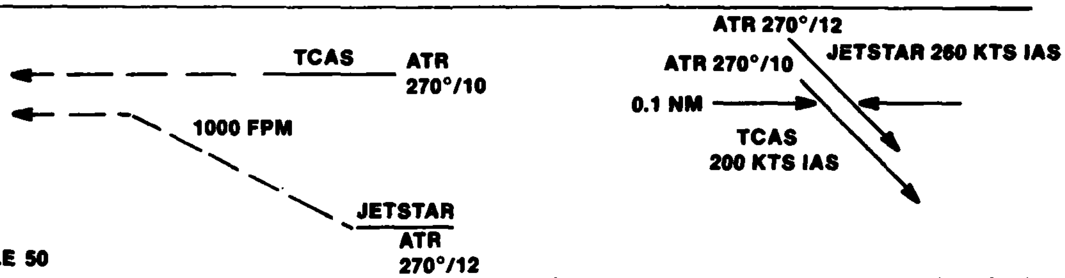
PROFILE 47



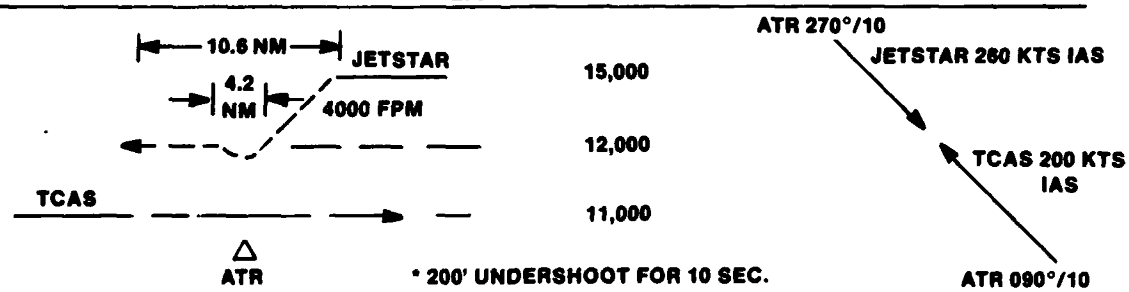
PROFILE 48



PROFILE 49



PROFILE 50



PROFILE 51

ENCOUNTER DESCRIPTIONS ACCEPTANCE TEST

Encounter	Description	Expected Advisory Sequence
1	Head on - both levels	Removed 3 s after closest point of approach (CPA), climb = 27 s
2	Head on - both levels	Removed = 2 s after CPA, descend = 27 s
3	Advisory inhibit	Radar altimeter <12.5 V 700 ft change "Descend" to "Do Not Climb"
4	Head on - Both levels	Removed = 3 s after CPA, climb = 25 s
5	Head on - Both levels	Removed = 3 s after CPA, do not descend = 35 s
6	Advisory inhibit	Pressure altitude >34,000 ft change "Climb" to "Do Not Descend"
7	Head on - both levels Intruder is non-Mode C	Traffic advisory at = 45 s, removed = 2 s after CPA
8	Vertical rate - TCAS level	Removed = 3 s after CPA, do not descend = 29 s, vertical speed limit (VSL) 500 = 19 s, VSL 1000 = 9 s
9	Vertical rate - TCAS level	Removed = 2 s after CPA do not descend = 28 s, VSL 500 = 15 s, VSL 2000 = 5 s
10	Vertical rate - TCAS level	Removed = 2 s after CPA climb = 34 s VSL 2000 = 5 s
11	Vertical rate - intrude level	Do not climb = 27 s, VSL 5000 = 17 s, VSL 1000 = 7 s, removed = 2 s after CPA

ENCOUNTER DESCRIPTIONS ACCEPTANCE TEST (CONTINUED)

Encounter	Description	Expected Advisory Sequence
12	Vertical rate-intruder level	Do not climb = 28 s, VSL 500 = 15 s, VSL 2000 = 5 s, removed = 2 s after CPA
13	Vertical rate -	Descend = 34 s, VSL 2000 intruder level = 5, removed = 3 s after CPA
14	Vertical rate - TCAS level	Climb = 27 s, removed = 2 s after CPA
15	Advisory inhibit	Do not descend = 27 s, removed = 2 s after CPA
16	Level off (firmness test)	Descend = 25 s, removed = 2 s after CPA
17	Level off (firmness test)	Descend = 25 s, removed = 2 s after CPA
18	Level off (TCAS abort)	Climb = 27 s, advisory not O.K. = 15 s, removed = 2 s after CPA
19	Popup (firmness, tracker test)	Resolution advisory delay = 6 s after pop-up
20	Tail chase	Descend = 25 s, removed at CPA
21	Tail chase	Descend = 25 s, removed at CPA

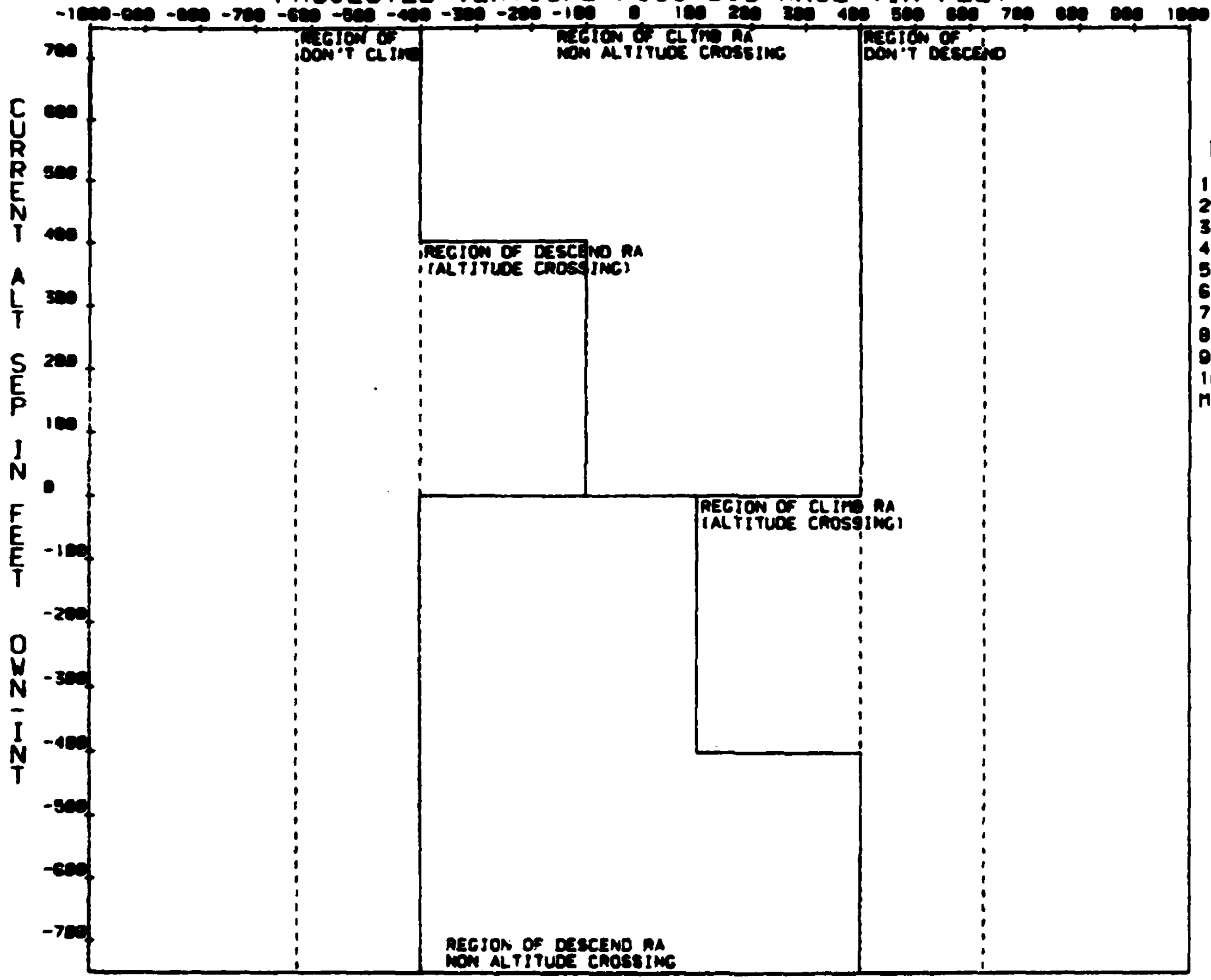
APPENDIX D

RESULTS OF THE CAS LOGIC EVALUATION

.. TEST FLIGHTS 5/24/83 - 7/13/83

PROJECTED VERTICAL MISS DISTANCE (IN FEET)

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

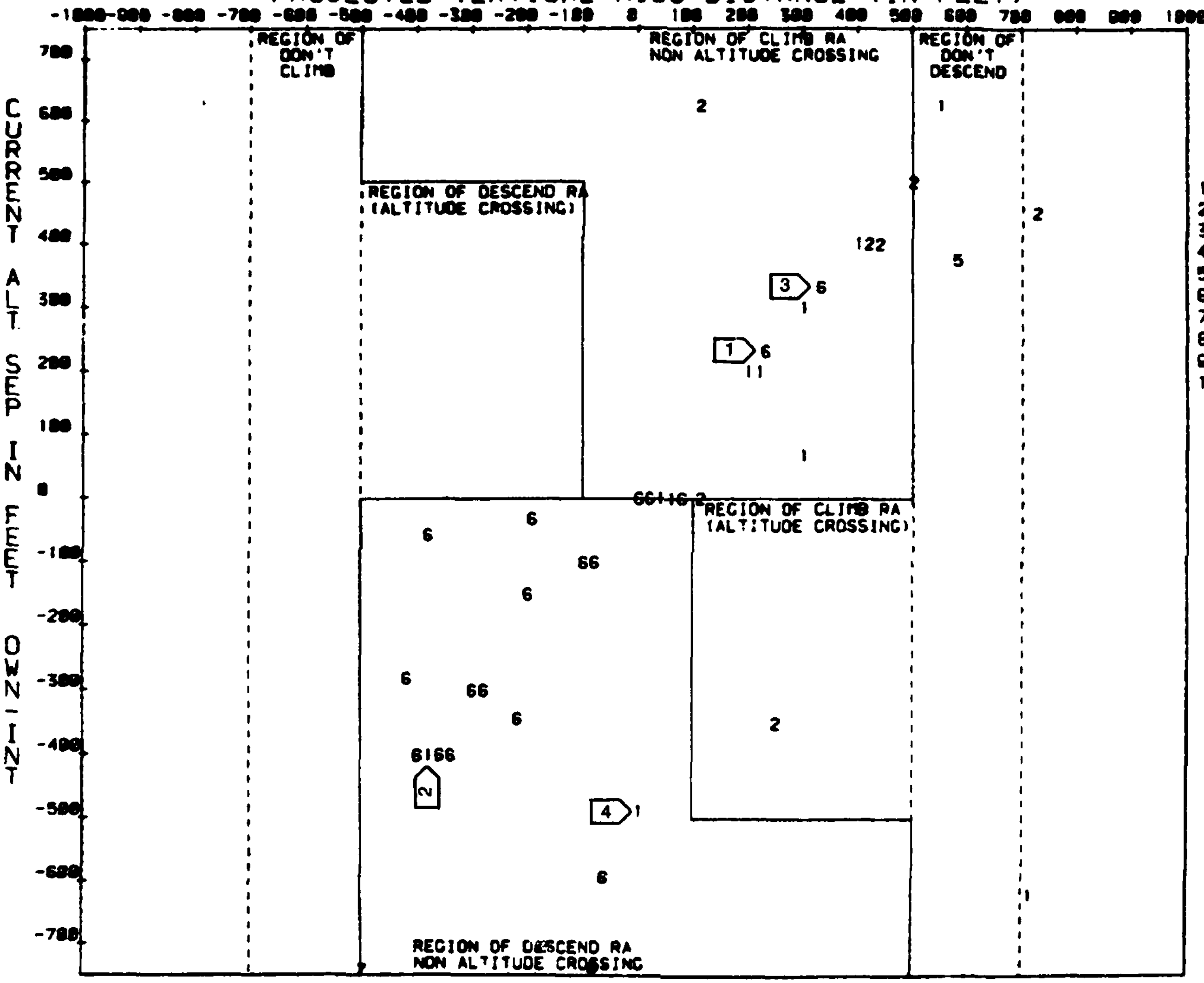
TOTAL ENCOUNTERS = 0

PROCESSING DATE: AUGUST 30, 1984 LAYER 1

ENGINEERING TEST FLIGHTS 5/24/83 - 7/13/83

PROJECTED VERTICAL MISS DISTANCE (IN FEET)

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



PROCESSING DATE: SEPT 14, 1984

LAYER 2

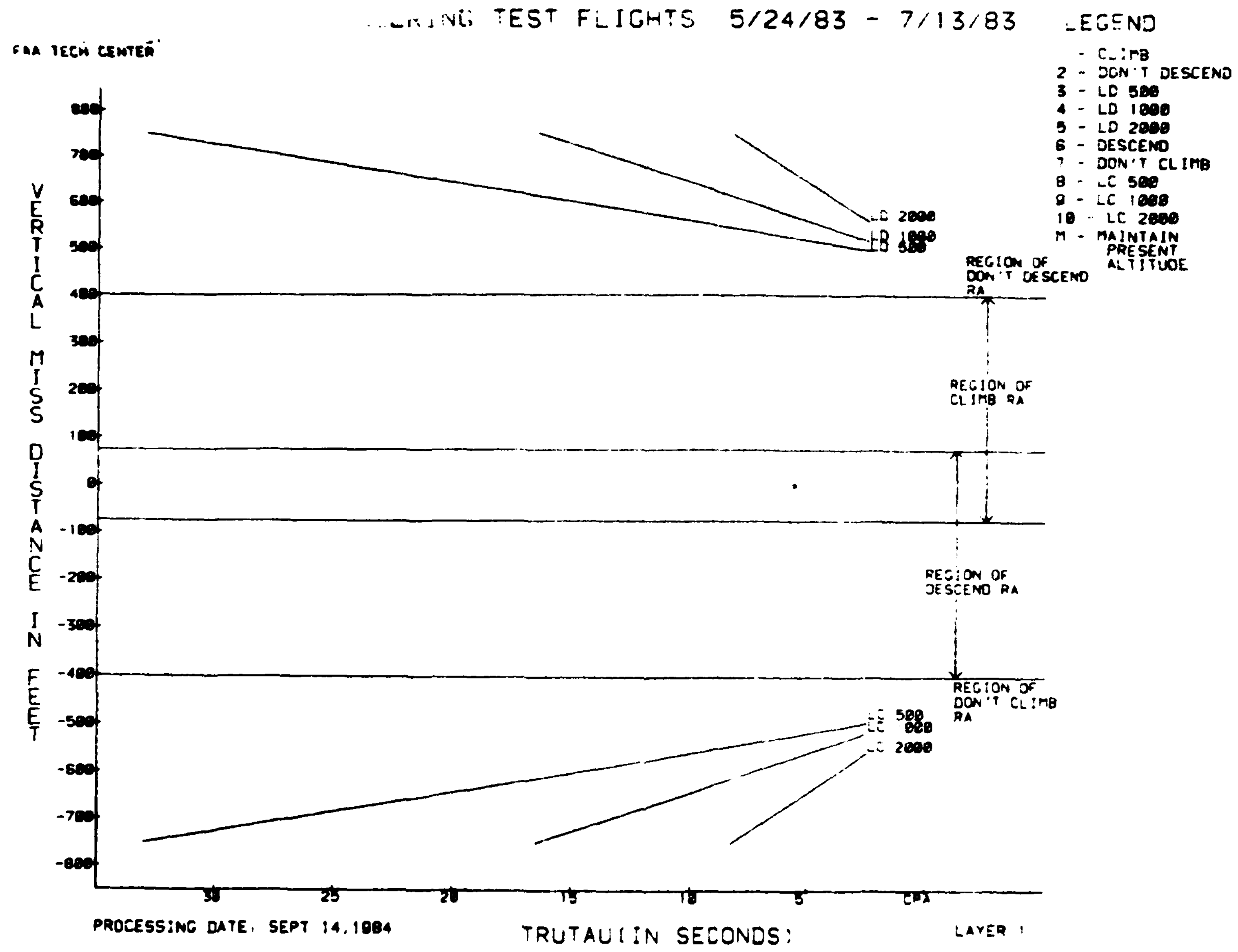
LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

TOTAL ENCOUNTERS = 40

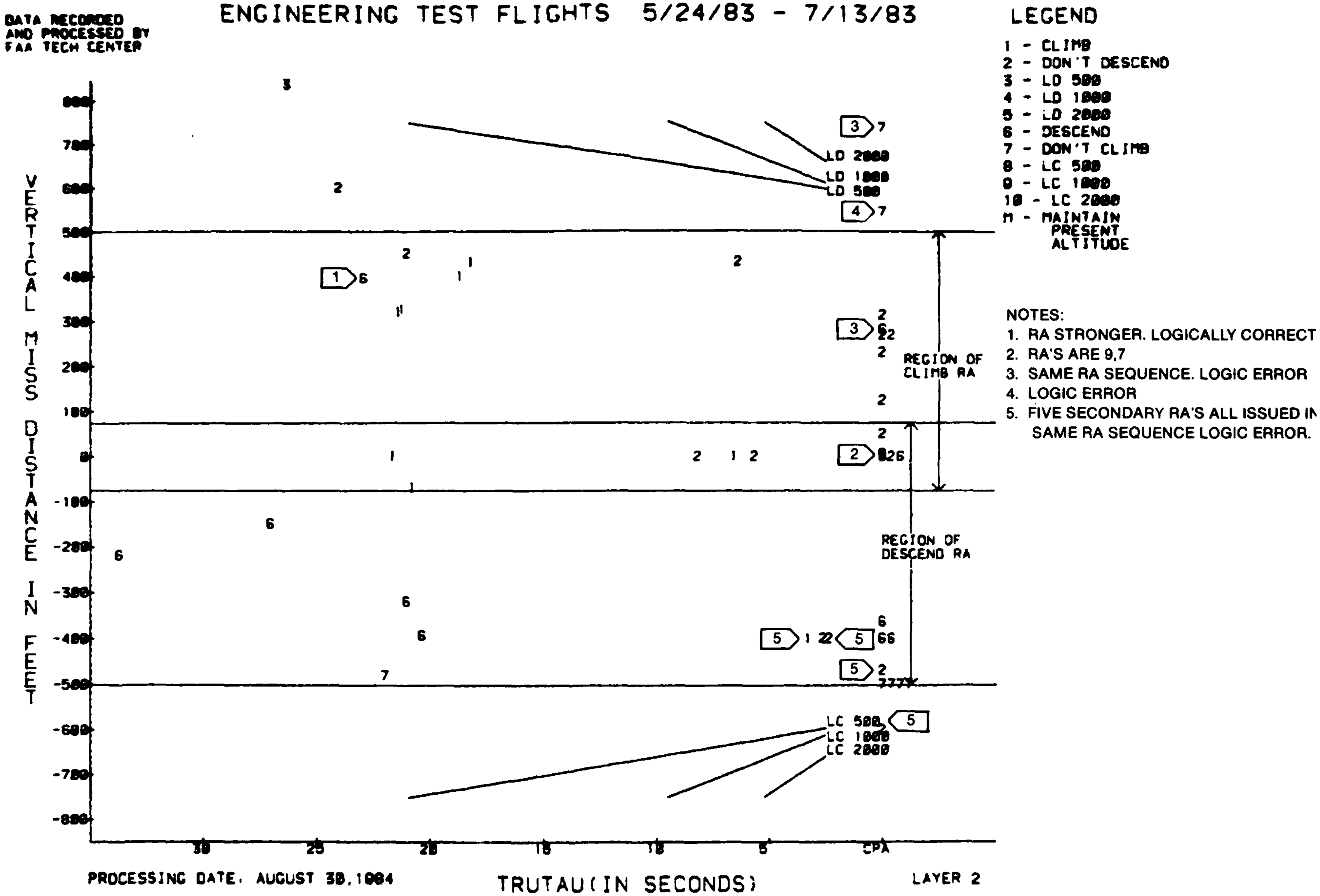
NOTES:

1. LOGIC ERROR 5/25/83
   UNIQUE ID=27
2. LOGIC ERROR 5/25/83
   UNIQUE ID=95
3. LOGIC ERROR 7/13/83
   UIQUE ID=194
4. 6/10/83 FTEG PLAYBACK PRODUC
   NO RA

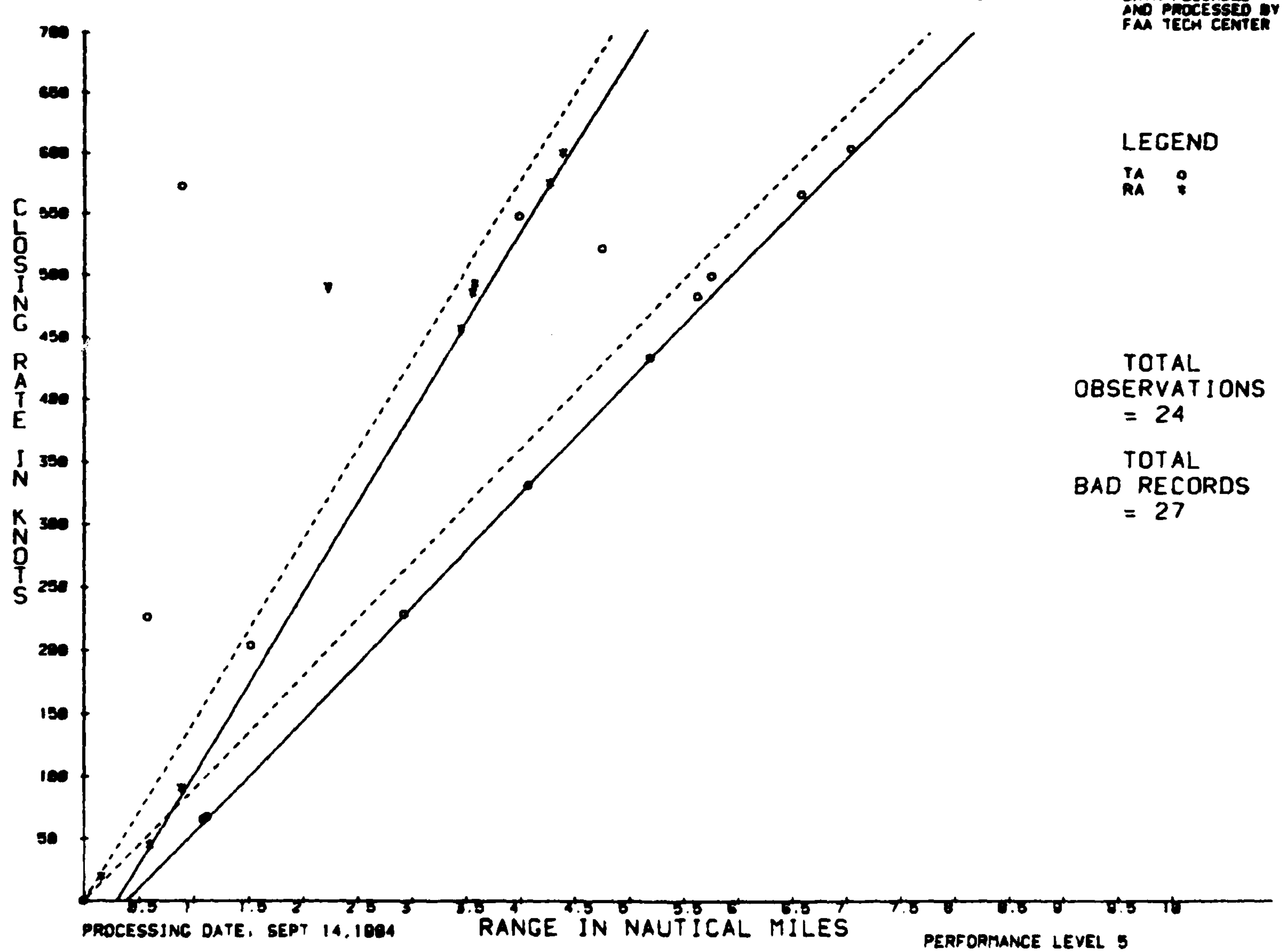


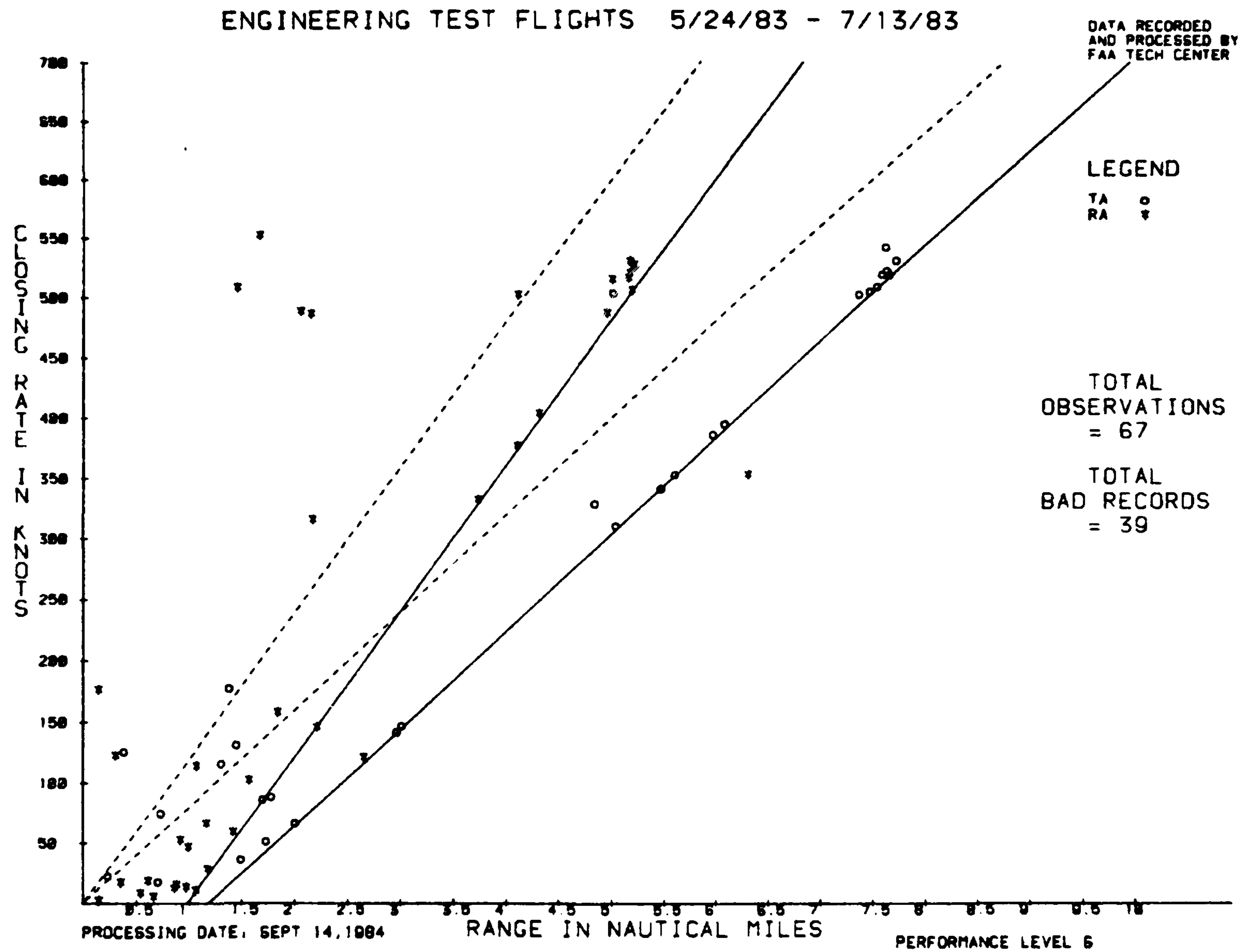
TEST FLIGHTS 5/24/83 - 7/13/83
LEGEND
- CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
FAA TECH CENTER
VERTICAL MISS DISTANCE IN FEET
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
LD 2000
LD 1000
LD 500
REGION OF DON'T DESCEND RA
REGION OF CLIMB RA
REGION OF DESCEND RA
REGION OF DON'T CLIMB RA
LC 500
LC 2000
30
25
20
15
10
5
CPA
PROCESSING DATE: SEPT 14, 1984
TRUTAU (IN SECONDS)
LAYER 1

ENGINEERING TEST FLIGHTS 5/24/83 - 7/13/83



TEST FLIGHTS 5/24/83 - 7/13/83

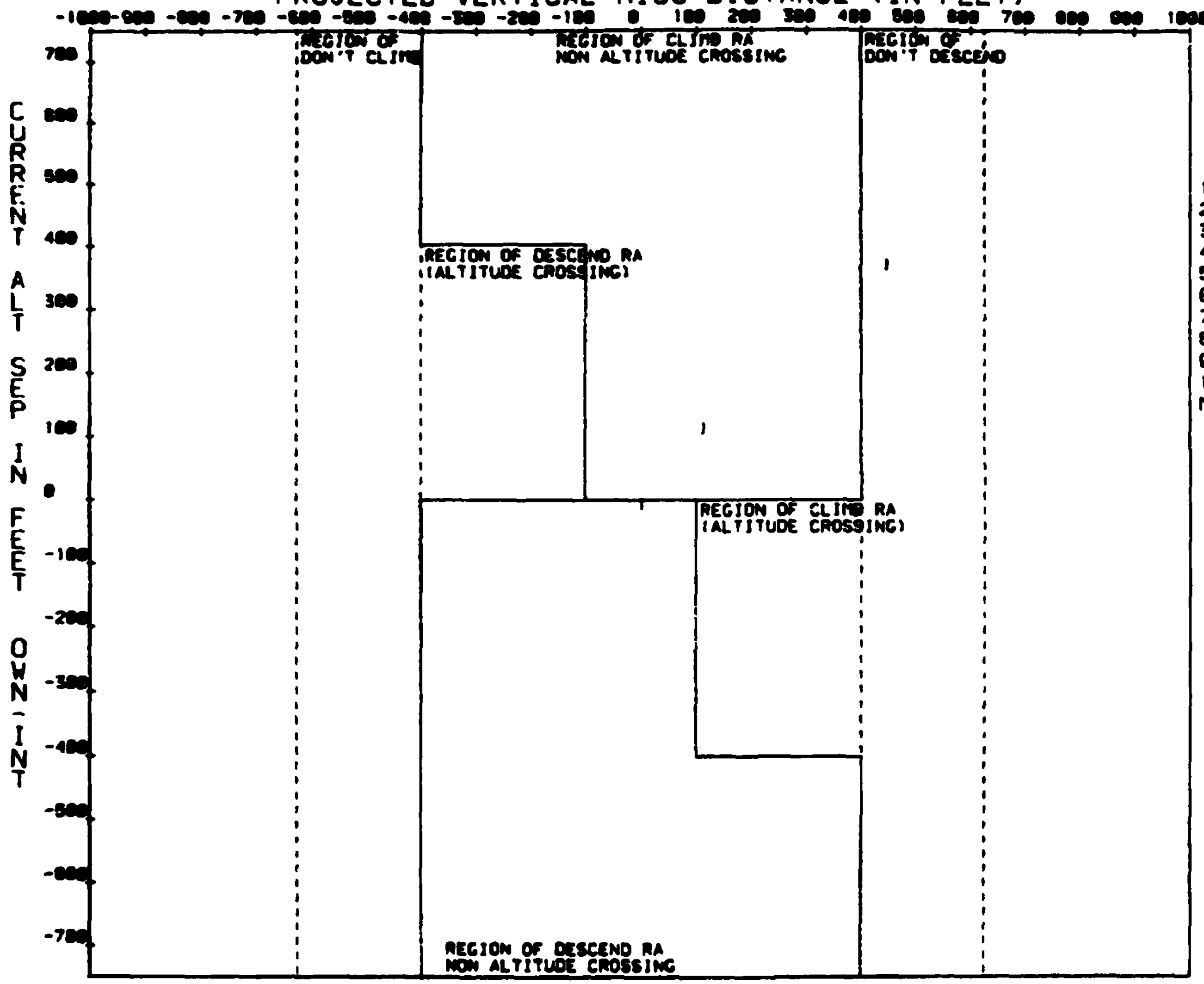



ENGINEERING TEST FLIGHTS 5/24/83 - 7/13/83
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
CLOSING RATE IN KNOTS
700
650
600
550
500
450
400
350
300
250
200
150
100
50
LEGEND
TA o
RA *
TOTAL OBSERVATIONS = 67
TOTAL BAD RECORDS = 39
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
RANGE IN NAUTICAL MILES
PROCESSING DATE: SEPT 14,1984
PERFORMANCE LEVEL 6

.. TEST FLIGHTS 10/7/83 - 10/18/83

PROJECTED VERTICAL MISS DISTANCE (IN FEET)

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

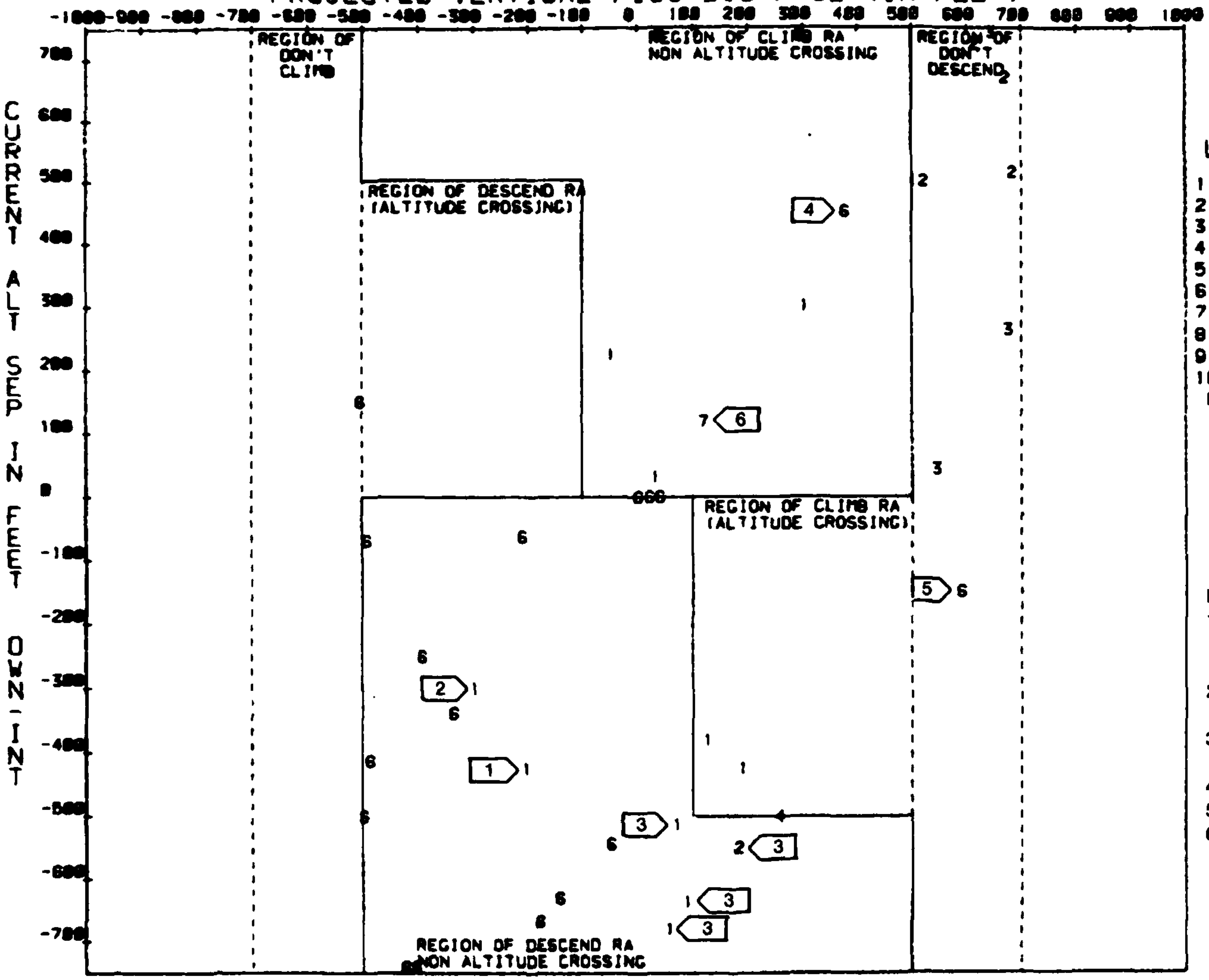
TOTAL ENCOUNTERS = 4

PROCESSING DATE: SEPT 5, 1984

LAYER 1

ENGINEERING TEST FLIGHTS 10/7/83 - 10/18/83

DATA RECORDED AND PROCESSED BY FAA TECH CENTER



PROCESSING DATE: SEPT 5, 1984

LAYER 2

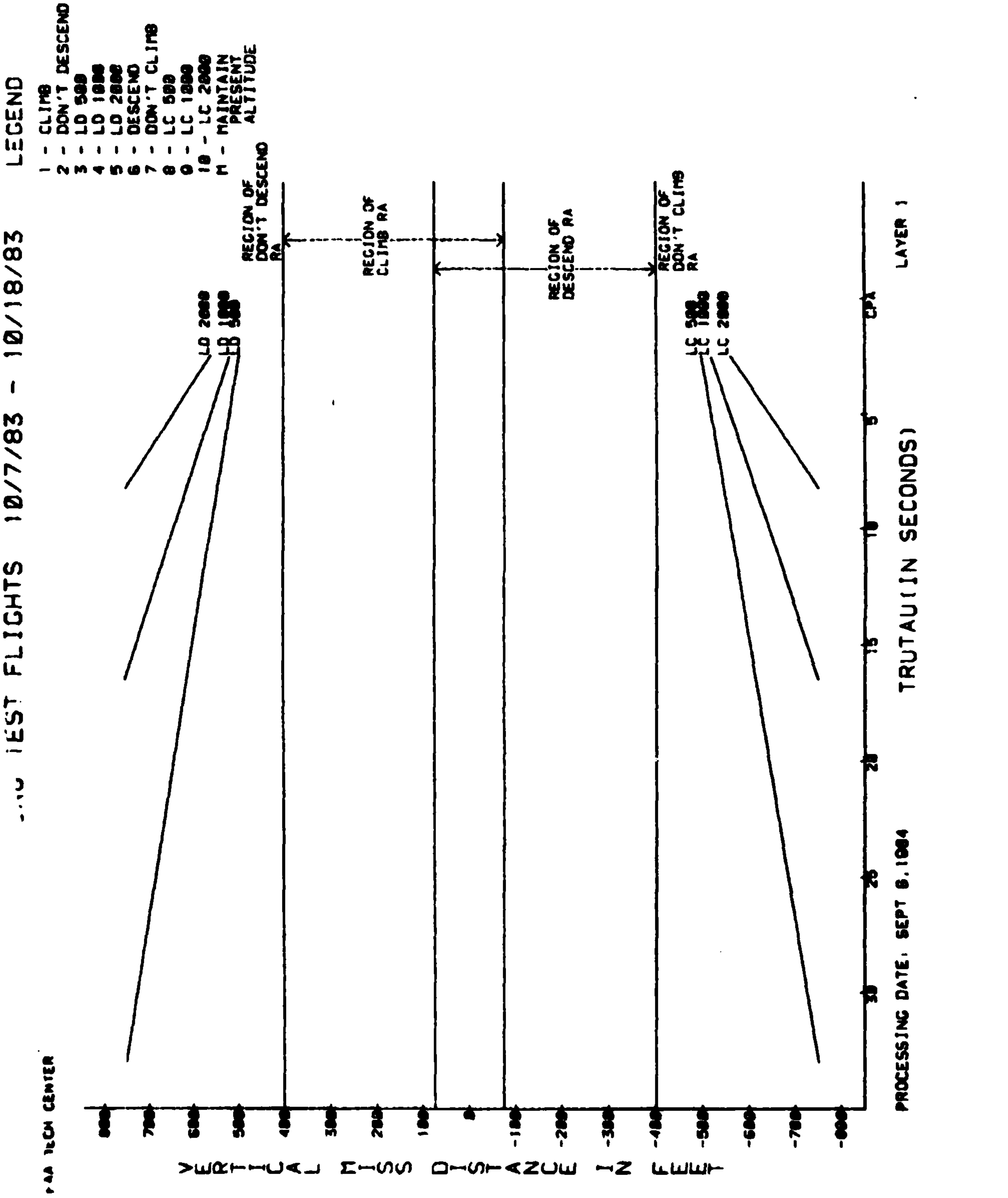
LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

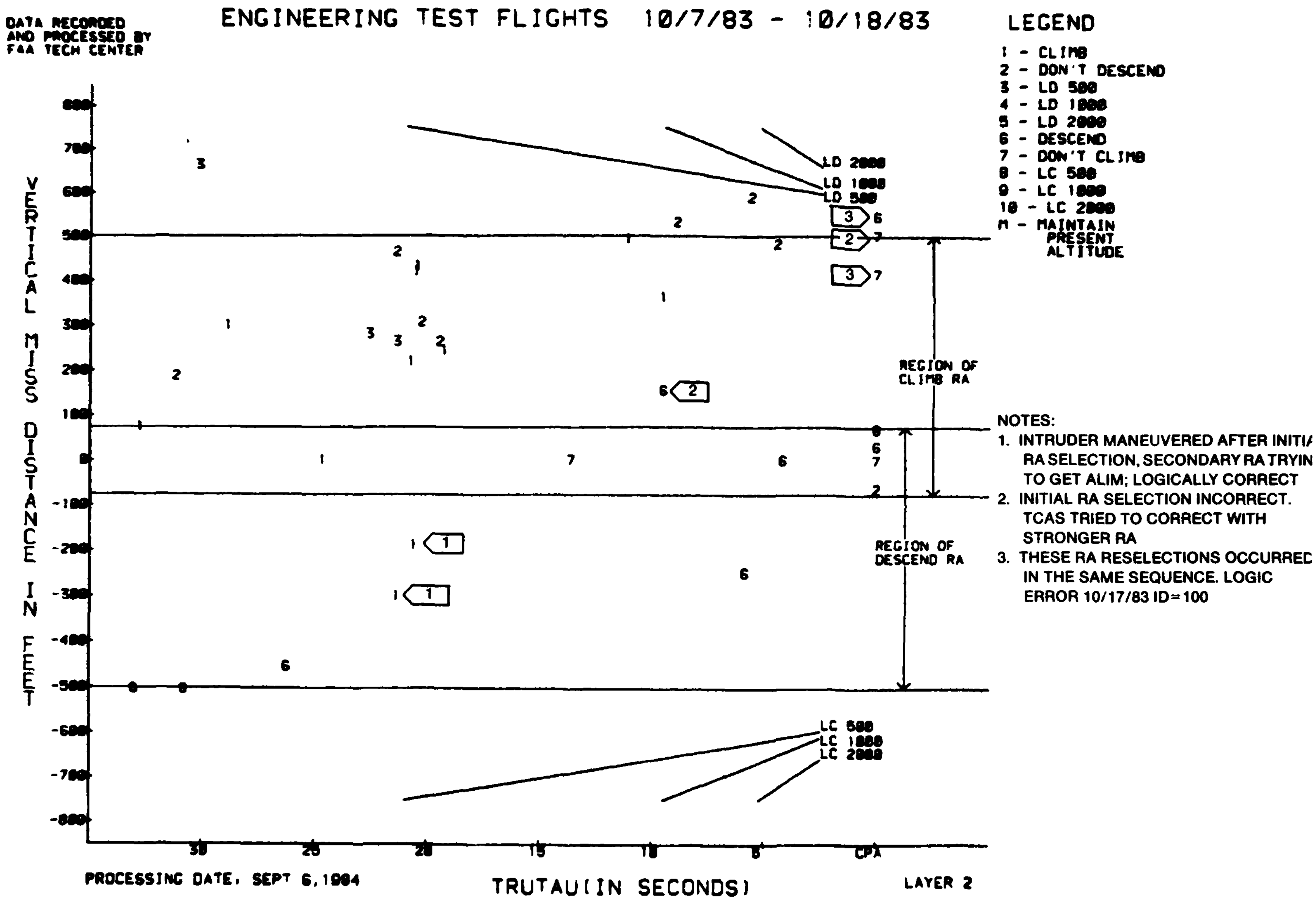
TOTAL ENCOUNTERS = 41

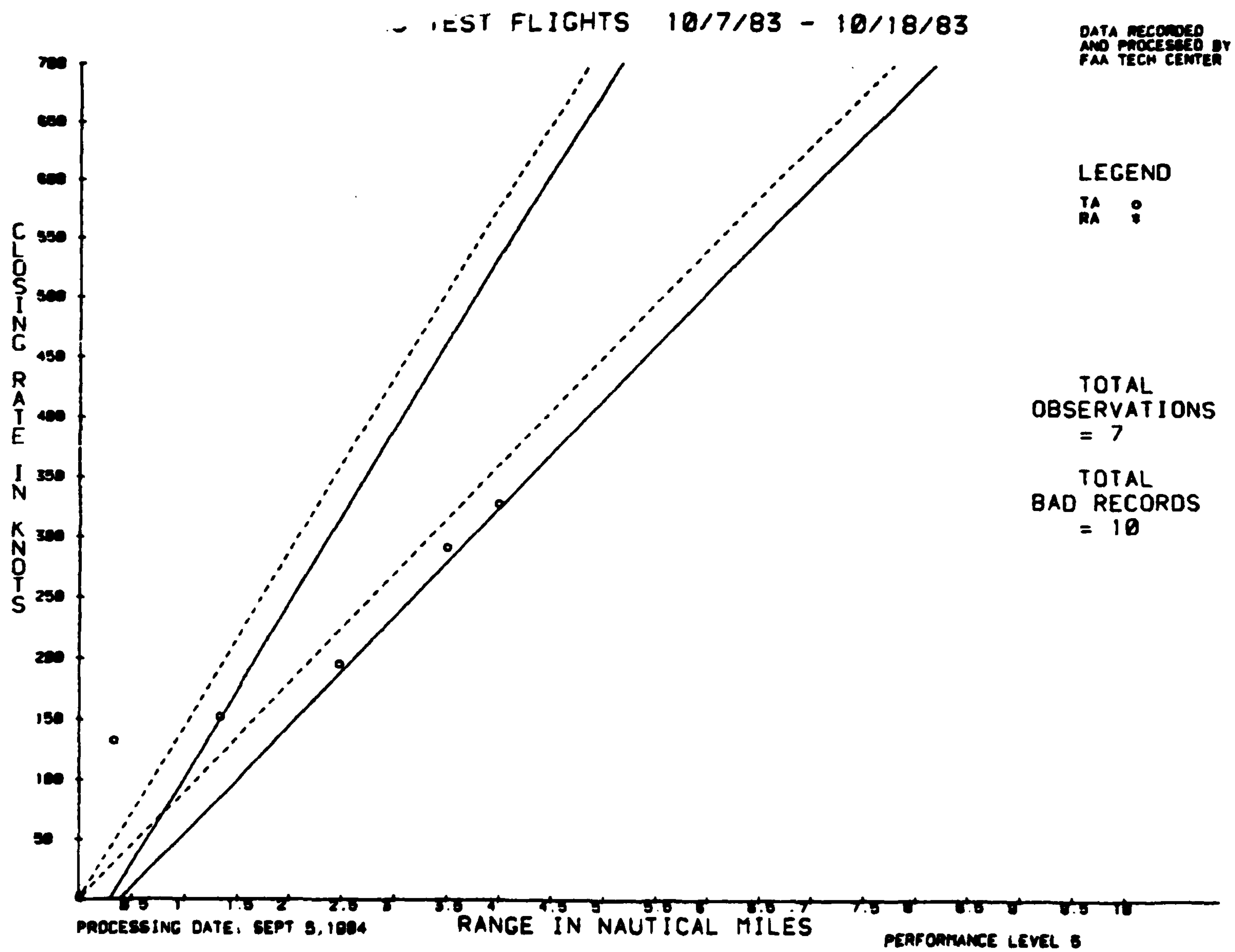
NOTES:

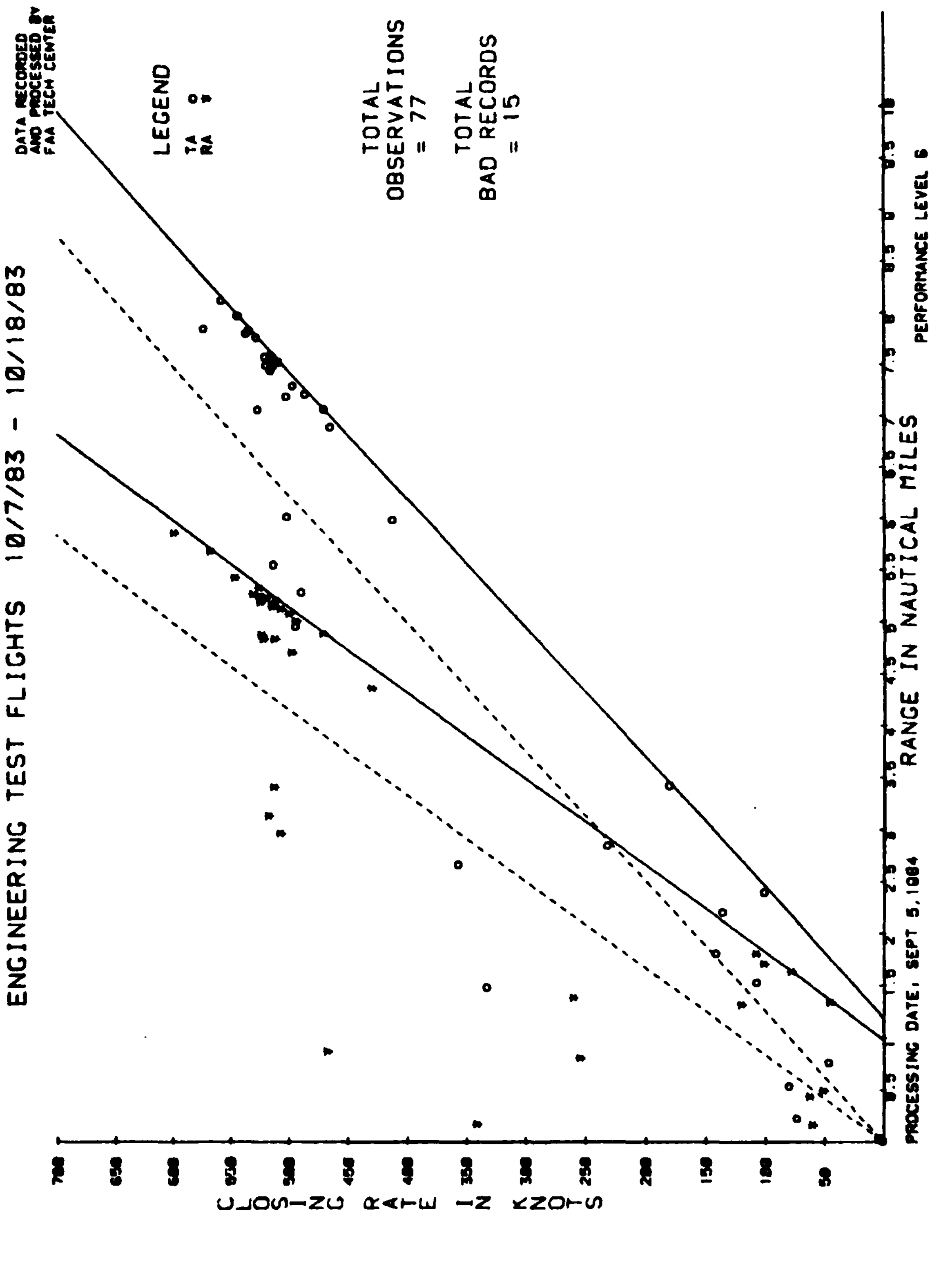
1. RA PICKED ON LOW FIRNESS. RATE BOUND LOGIC INVOKED. ABORTED LOGICALLY CORRECT
2. DATA TAPE 10/18/83 ID=75 LOGICAL ERROR
3. ALTITUDE CROSSING, LOGICALLY CORRECT
4. LOGIC ERROR 10/18/83 ID=31
5. LOGIC ERROR 10/17/83 ID=94
6. LOGIC ERROR 10/07/83 ID=85



... TEST FLIGHTS 10/7/83 - 10/18/83
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
REGION OF DON'T DESCEND RA
REGION OF CLIMB RA
REGION OF DESCEND RA
REGION OF DON'T CLIMB RA
LD 2000
LD 1000
LD 500
LC 500
LC 1000
LC 2000
CPA
VERTICAL MISS DISTANCE IN FEET
TRUTAU (IN SECONDS)
LAYER 1
PROCESSING DATE: SEPT 6,1984
FAA TECH CENTER


ENGINEERING TEST FLIGHTS 10/7/83 - 10/18/83
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
VERTICAL MISS DISTANCE IN FEET
TRUTAU (IN SECONDS)
REGION OF CLIMB RA
REGION OF DESCEND RA
LD 2000
LD 1000
LD 500
LC 500
LC 1000
LC 2000
CPA
PROCESSING DATE, SEPT 6, 1984
LAYER 2
NOTES:
1. INTRUDER MANEUVERED AFTER INITIA RA SELECTION, SECONDARY RA TRYIN TO GET ALIM; LOGICALLY CORRECT
2. INITIAL RA SELECTION INCORRECT. TCAS TRIED TO CORRECT WITH STRONGER RA
3. THESE RA RESELECTIONS OCCURREC IN THE SAME SEQUENCE. LOGIC ERROR 10/17/83 ID=100

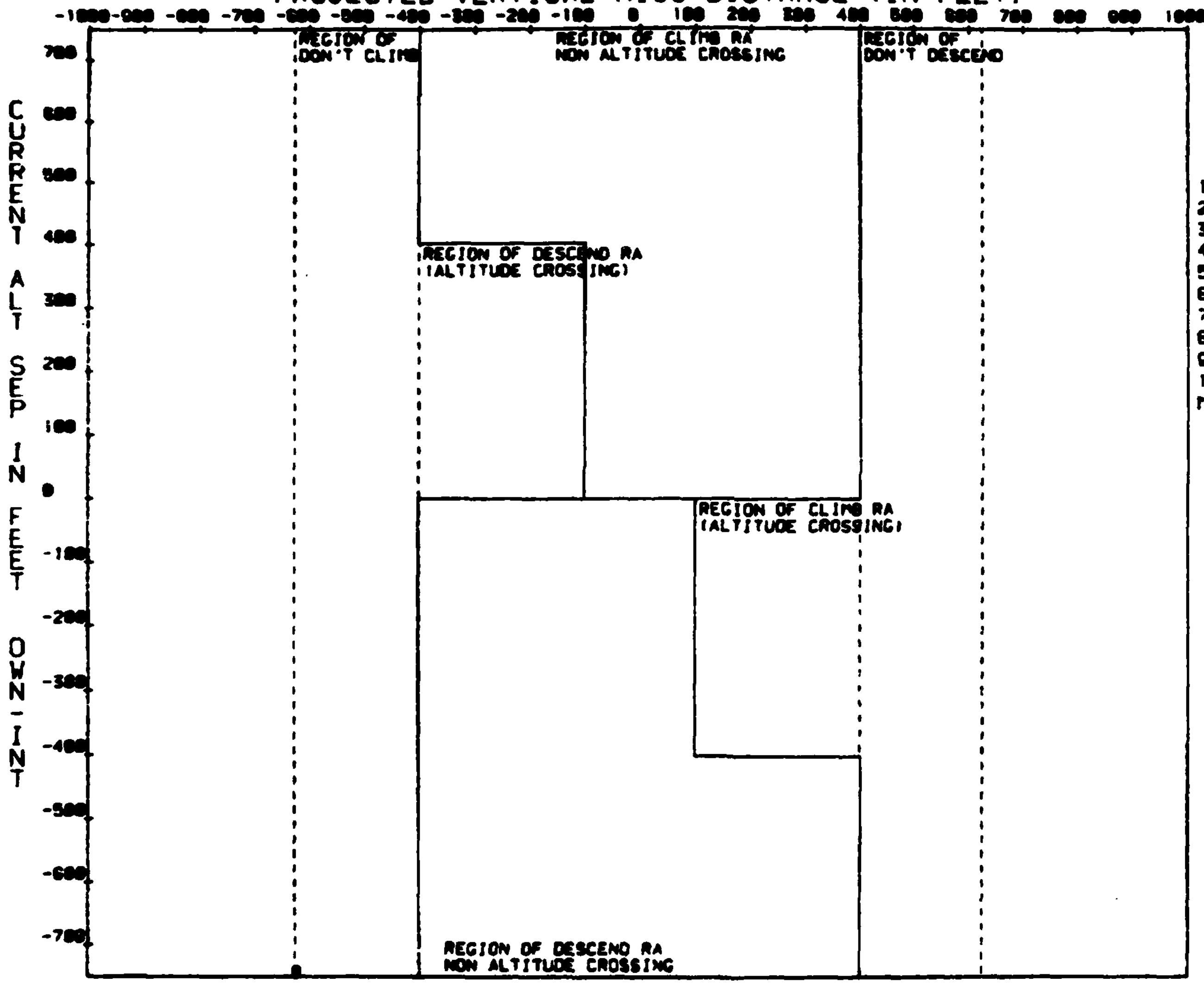

EST FLIGHTS 10/7/83 - 10/18/83
DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER
LEGEND
TA o
RA *
TOTAL
OBSERVATIONS
= 7
TOTAL
BAD RECORDS
= 10
CLOSING RATE IN KNOTS
700
650
600
550
500
450
400
350
300
250
200
150
100
50
RANGE IN NAUTICAL MILES
PROCESSING DATE, SEPT 5,1984
PERFORMANCE LEVEL 6


ENGINEERING TEST FLIGHTS 10/7/83 - 10/18/83
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
LEGEND
TA o
RA *
TOTAL OBSERVATIONS = 77
TOTAL BAD RECORDS = 15
CLOSING RATE IN KNOTS
RANGE IN NAUTICAL MILES
PROCESSING DATE, SEPT 5,1984
PERFORMANCE LEVEL 6

...ING TEST FLIGHTS 11/8/83 - 11/30/83

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER

PROJECTED VERTICAL MISS DISTANCE (IN FEET)



LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

TOTAL ENCOUNTERS = 1

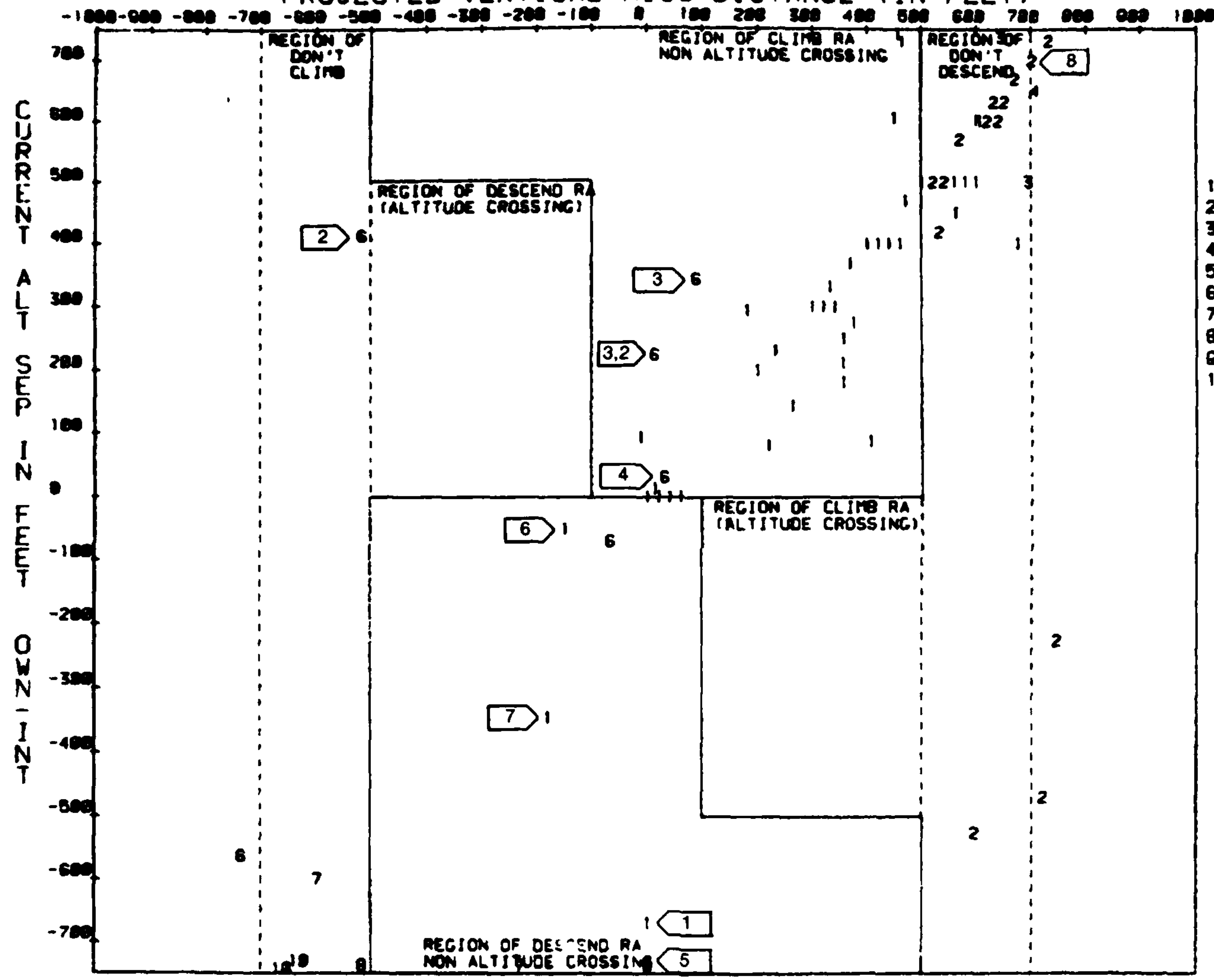
PROCESSING DATE: SEPT 5, 1984

LAYER 1

ENGINEERING TEST FLIGHTS 11/8/83 - 11/30/83

PROJECTED VERTICAL MISS DISTANCE (IN FEET)

DATA RECORDED AND PROCESSED BY FAA TECH CENTER



PROCESSING DATE: SEPT 5, 1984

LAYER 2

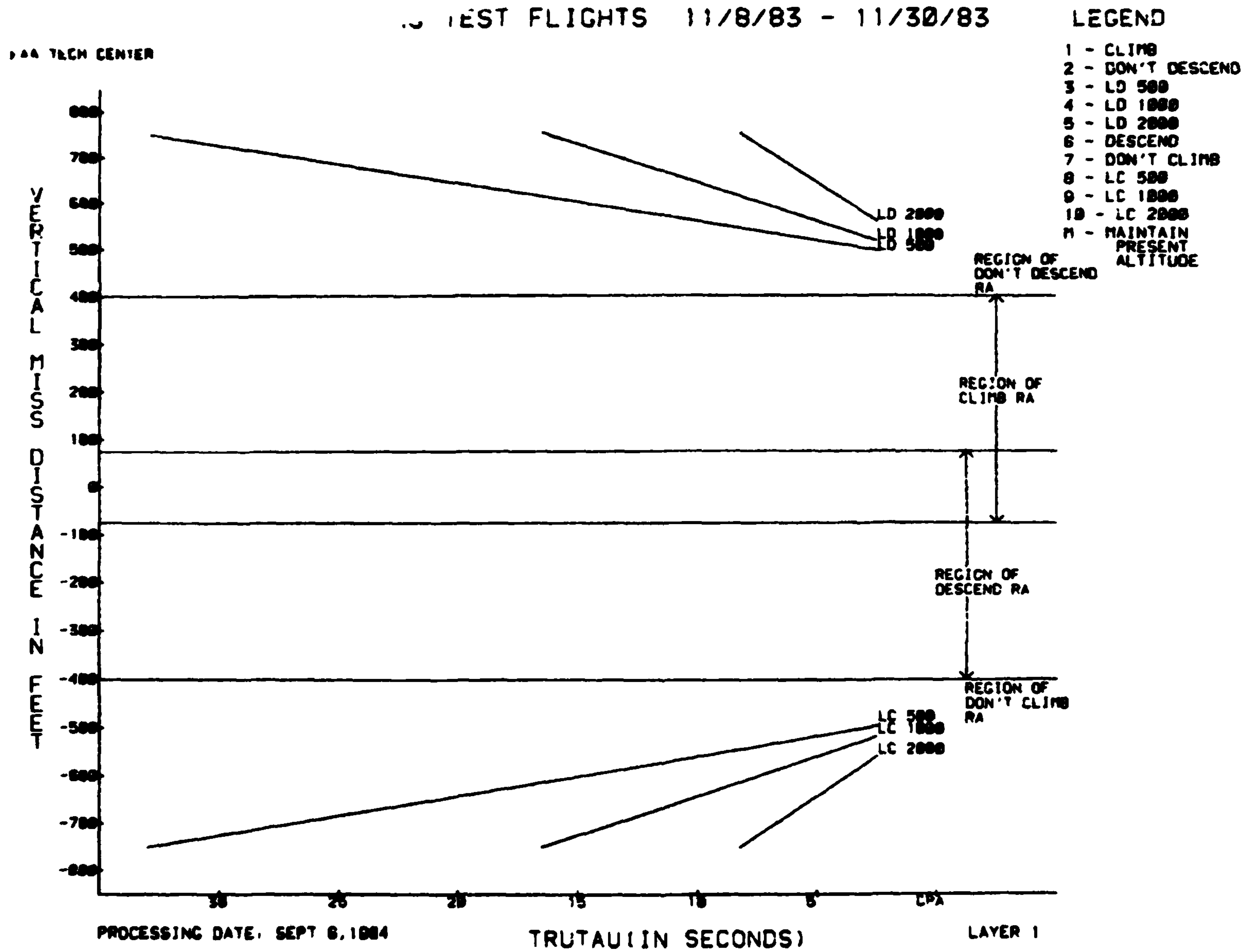
LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

TOTAL ENCOUNTERS = 70

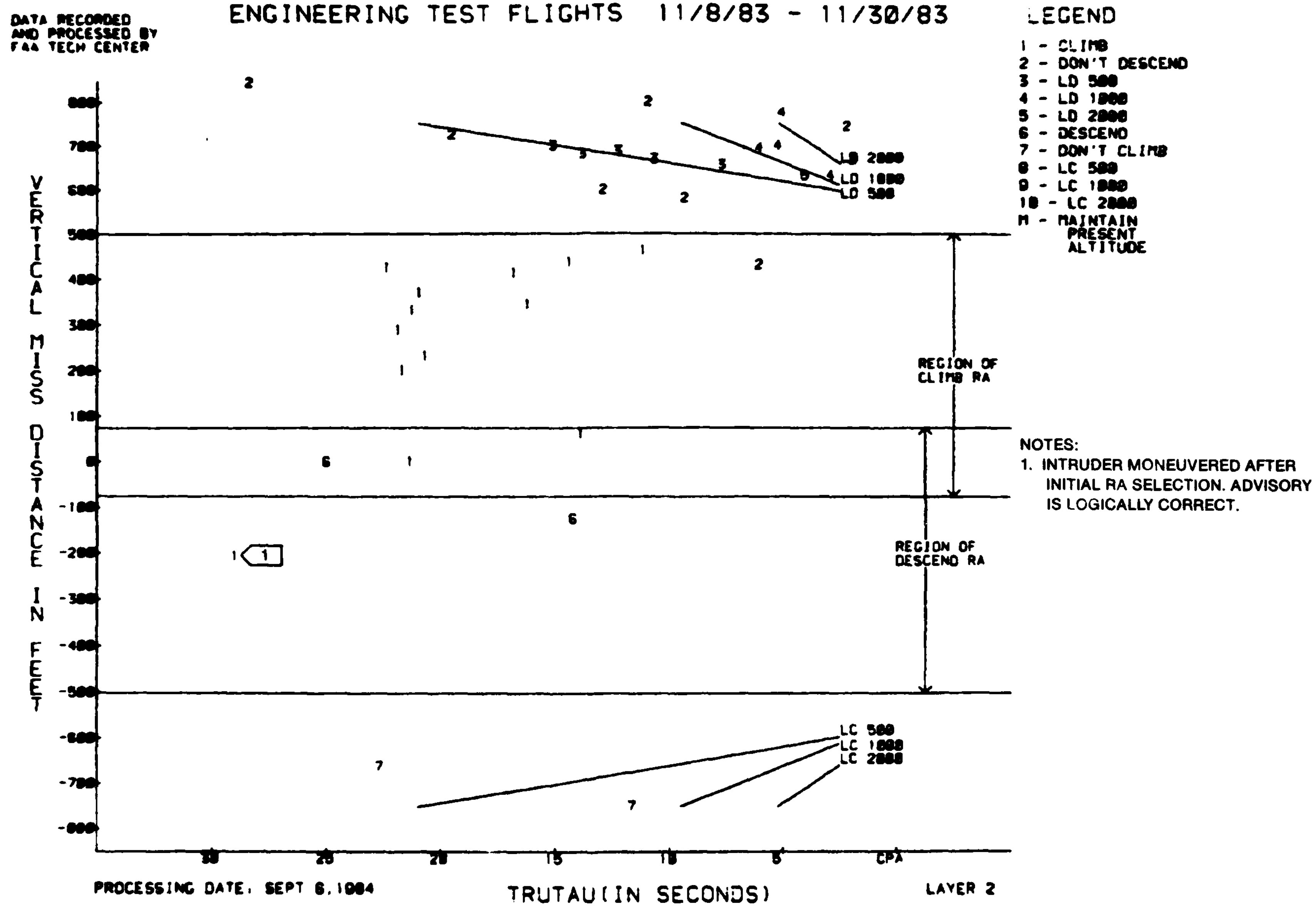
NOTES:

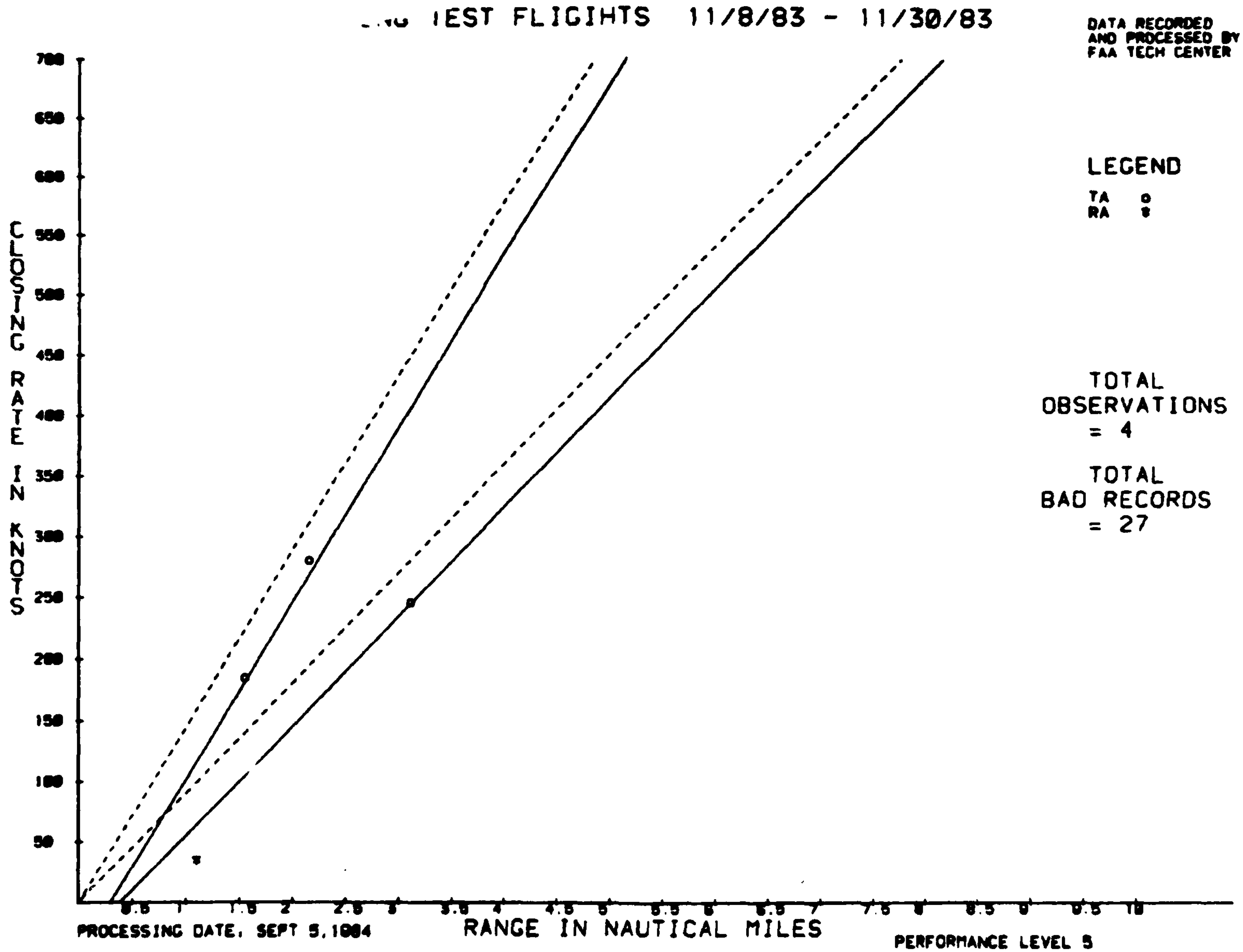
1. LOGIC ERROR 11/08/83 ID=31
2. TCAS ABORT
3. LOGICALLY CORRECT; RA PICKED ON LOW FIRMNESS
4. LOGIC ERROR 11/08/83 ID=72
5. TWO RA CODES APPEAR GARBLED BY THE TEXT? THEY ARE "6" AND "7"; BOTH LOGICALLY CORRECT. THE DESCEND RA RESULTED IN ABORT.
6. TIME OF DAY RECORDING PROBLEM, CORRECT RA.
7. ALTITUDE CROSSING RA, LOGICALLY CORRECT
8. SEE NOTE 1 ON PAGE D 16.

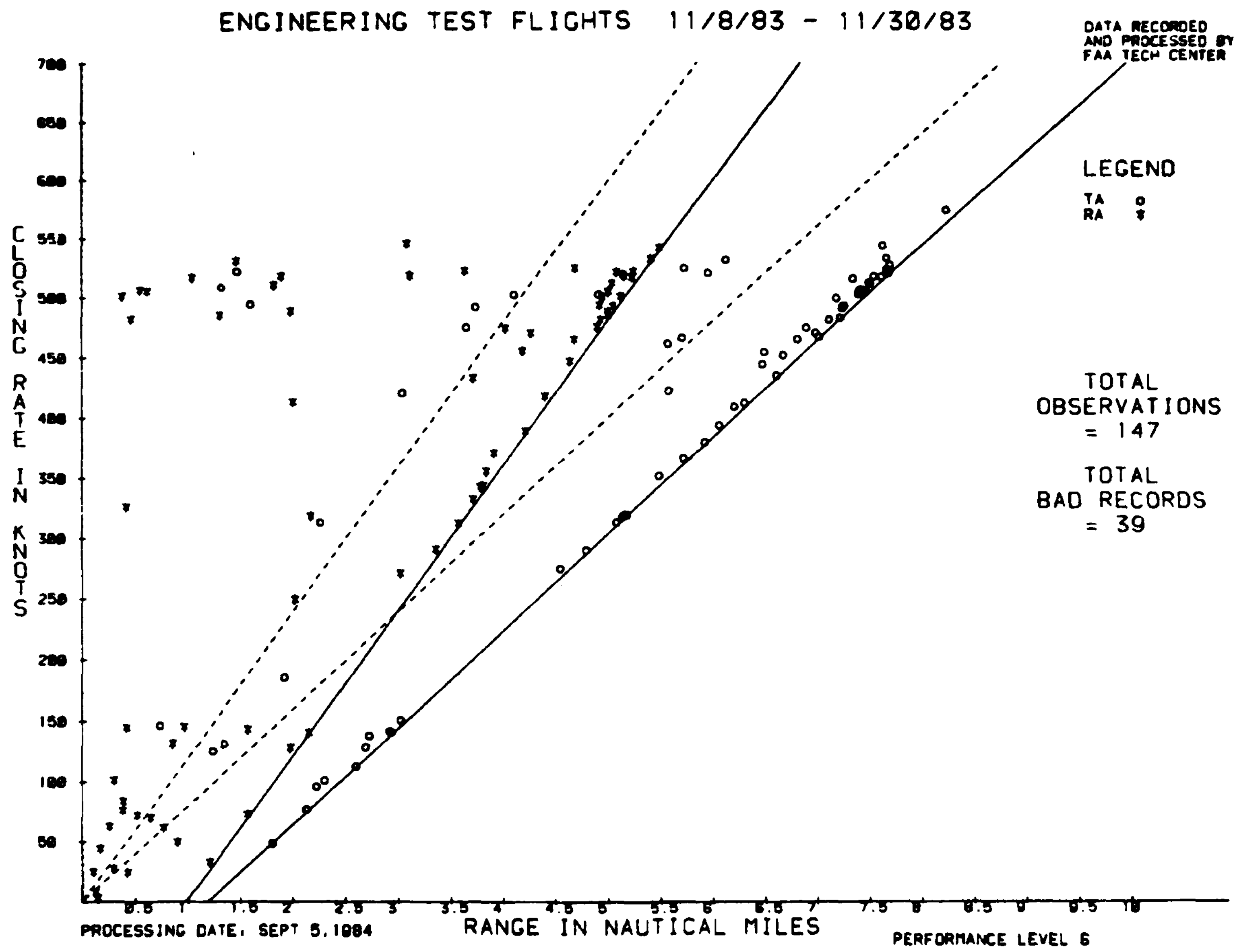


TEST FLIGHTS 11/8/83 - 11/30/83
FAA TECH CENTER
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
LD 2000
LD 1000
LD 500
REGION OF DON'T DESCEND RA
REGION OF CLIMB RA
REGION OF DESCEND RA
REGION OF DON'T CLIMB RA
LC 500
LC 1000
LC 2000
VERTICAL MISS DISTANCE IN FEET
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
30
25
20
15
10
5
CPA
PROCESSING DATE, SEPT 6,1984
TRUTAU(IN SECONDS)
LAYER 1

ENGINEERING TEST FLIGHTS 11/8/83 - 11/30/83



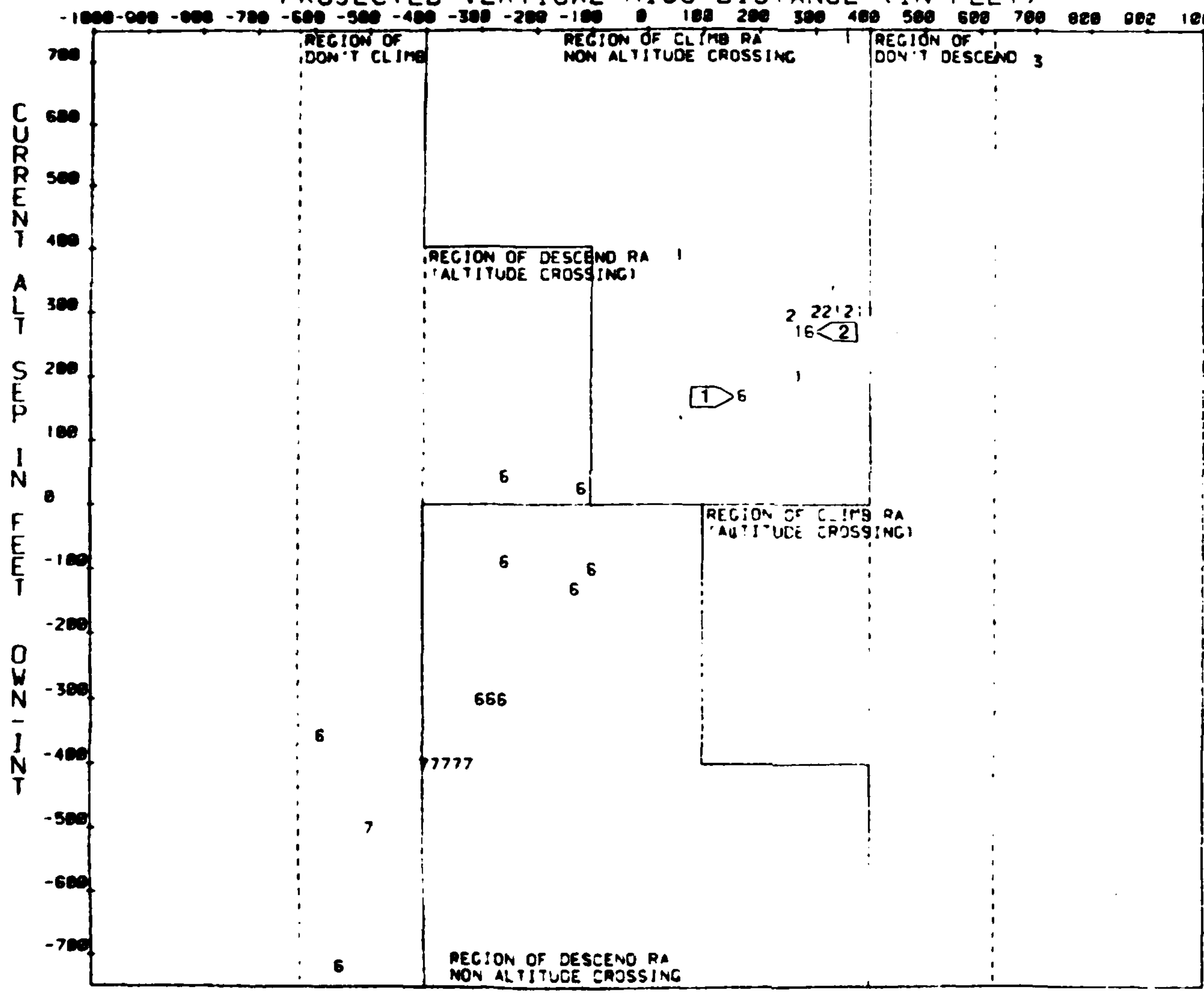

IEST FLIGIHTS 11/8/83 - 11/30/83
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
LEGEND
TA o
RA *
TOTAL OBSERVATIONS = 4
TOTAL BAD RECORDS = 27
CLOSING RATE IN KNOTS
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
PROCESSING DATE, SEPT 5,1984
RANGE IN NAUTICAL MILES
PERFORMANCE LEVEL 5


ENGINEERING TEST FLIGHTS 11/8/83 - 11/30/83
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
LEGEND
TA o
RA *
TOTAL OBSERVATIONS = 147
TOTAL BAD RECORDS = 39
CLOSING RATE IN KNOTS
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
RANGE IN NAUTICAL MILES
PROCESSING DATE, SEPT 5,1984
PERFORMANCE LEVEL 6

ENGINEERING TEST FLIGHTS 4/17/84 - 4/19/84

PROJECTED VERTICAL MISS DISTANCE (IN FEET)

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



PROCESSING DATE AUGUST 30, 1984

LAYER 1

LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

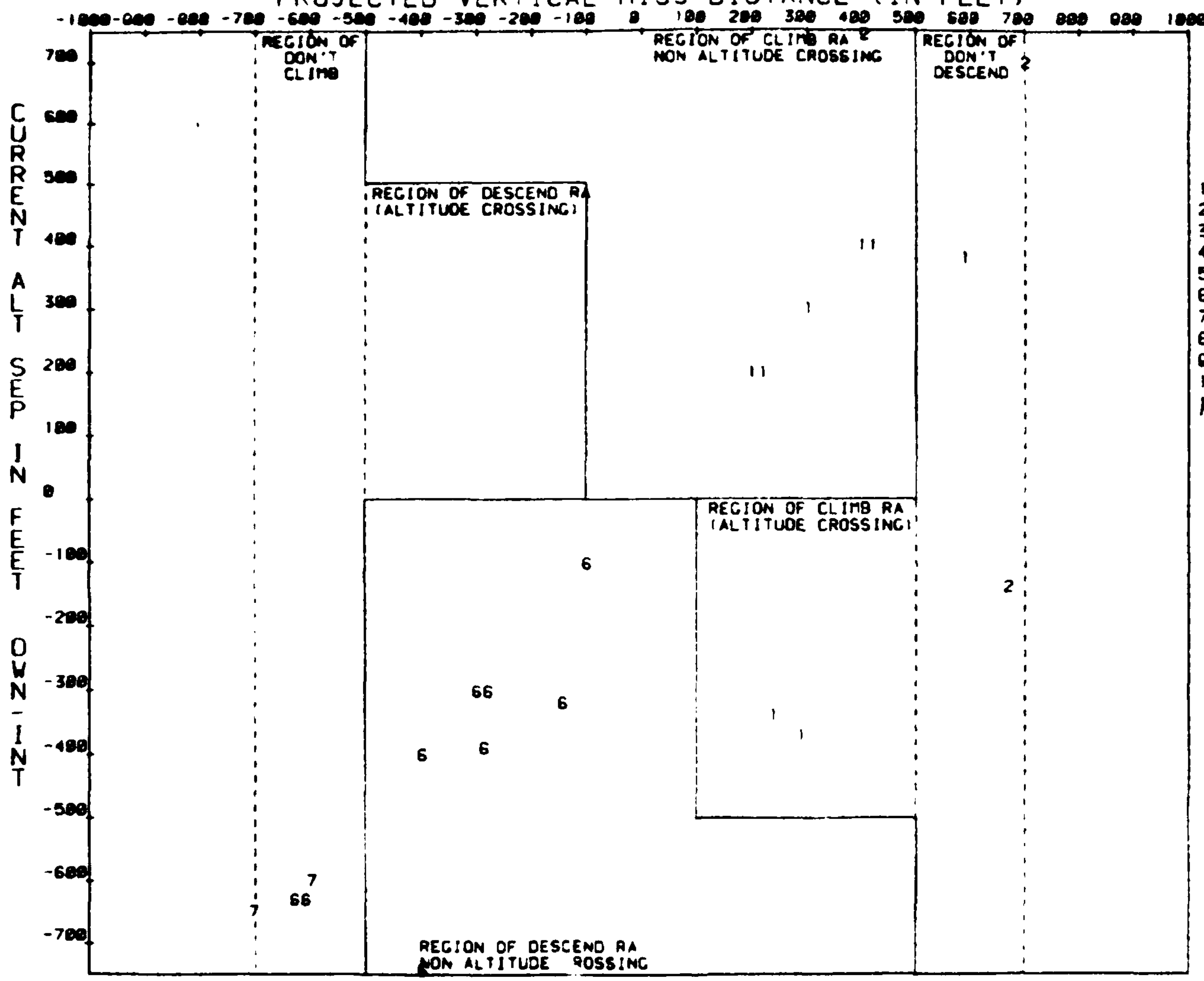
TOTAL ENCOUNTERS = 32

1. 4-18-84 ID #40
2. 4-19-84 ID #29 MAC FLAG SET

ENGINEERING TEST FLIGHTS 4/17/84 - 4/19/84

PROJECTED VERTICAL MISS DISTANCE (IN FEET)

DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER



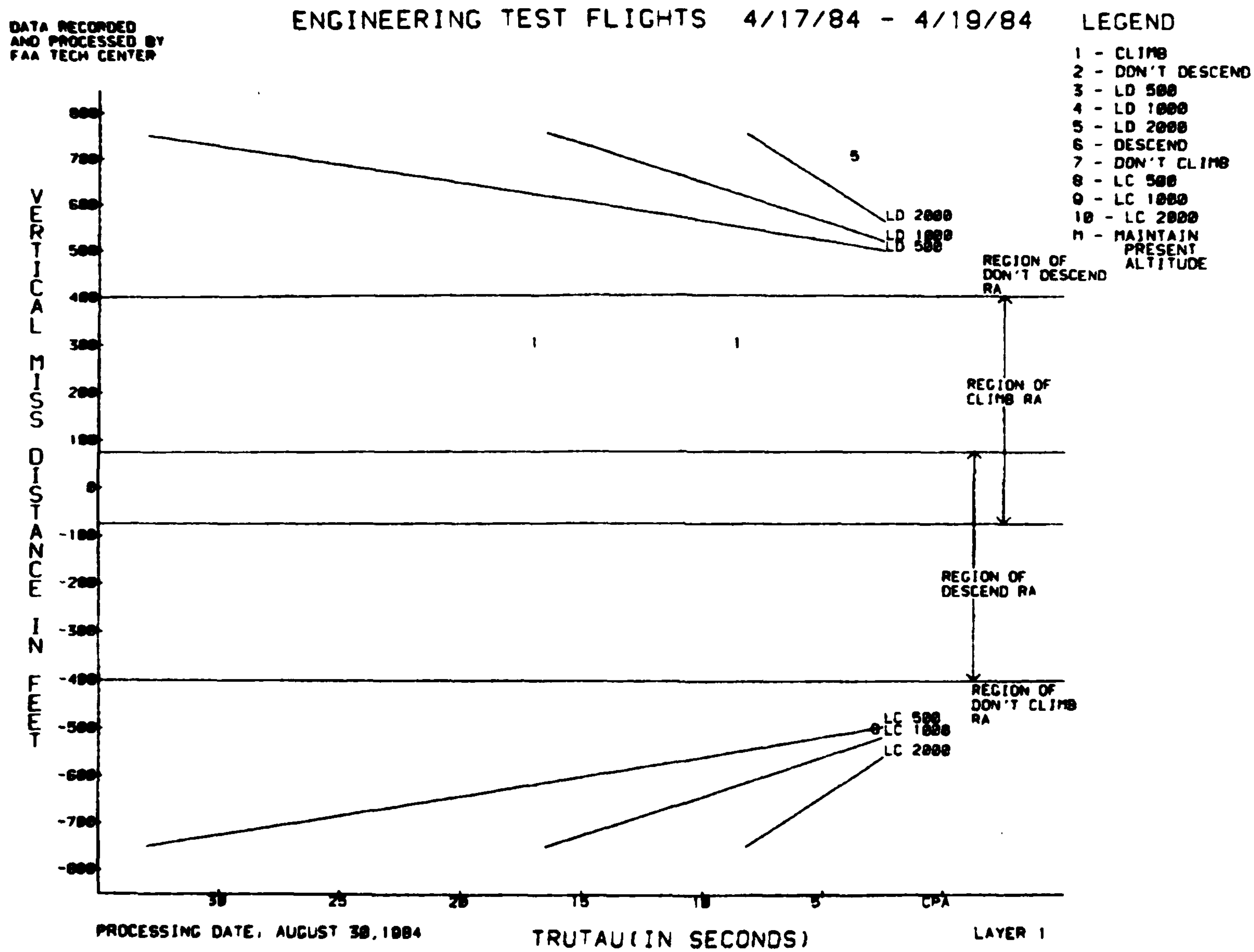
PROCESSING DATE: AUGUST 30, 1984

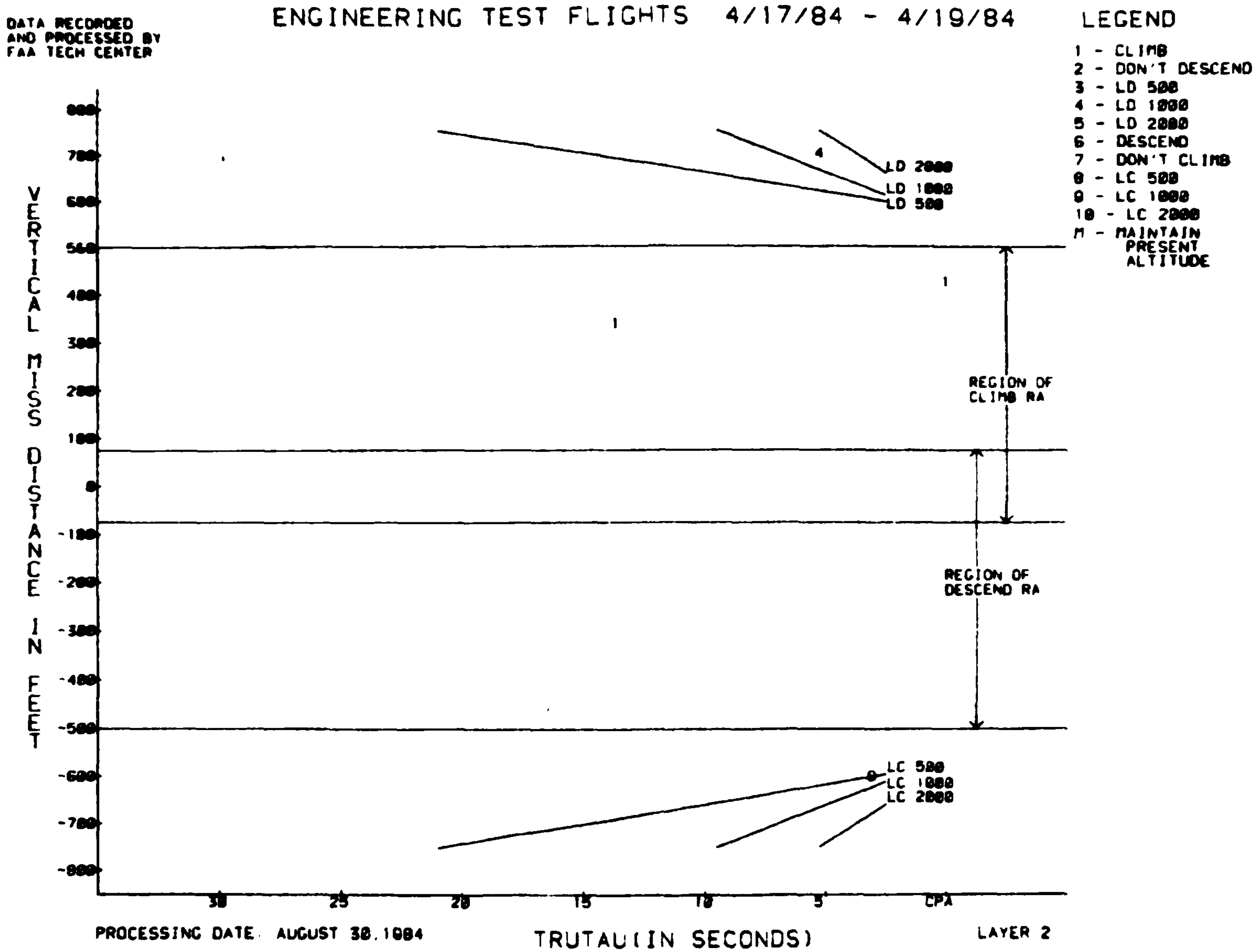
LAYER 2

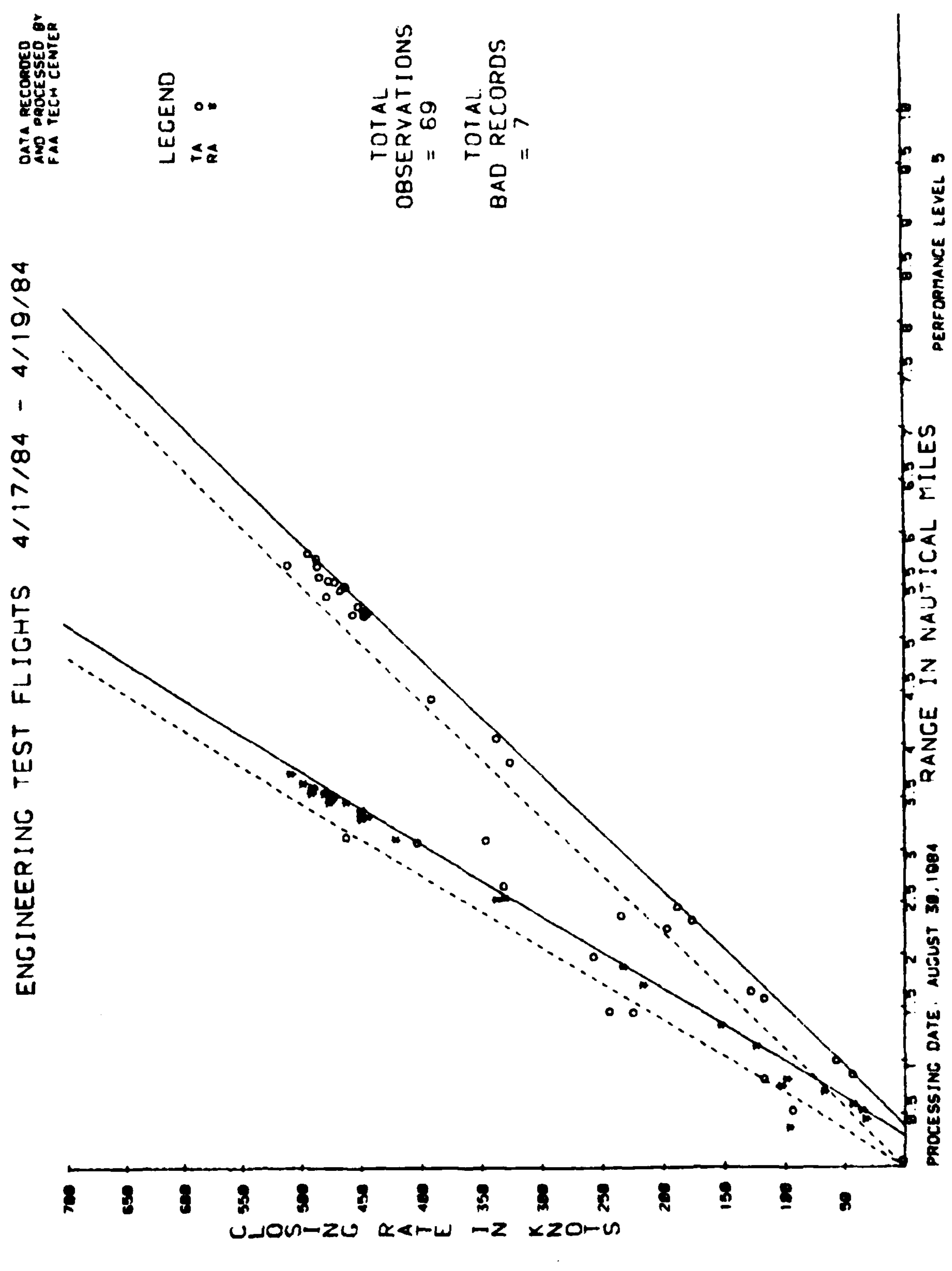
LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

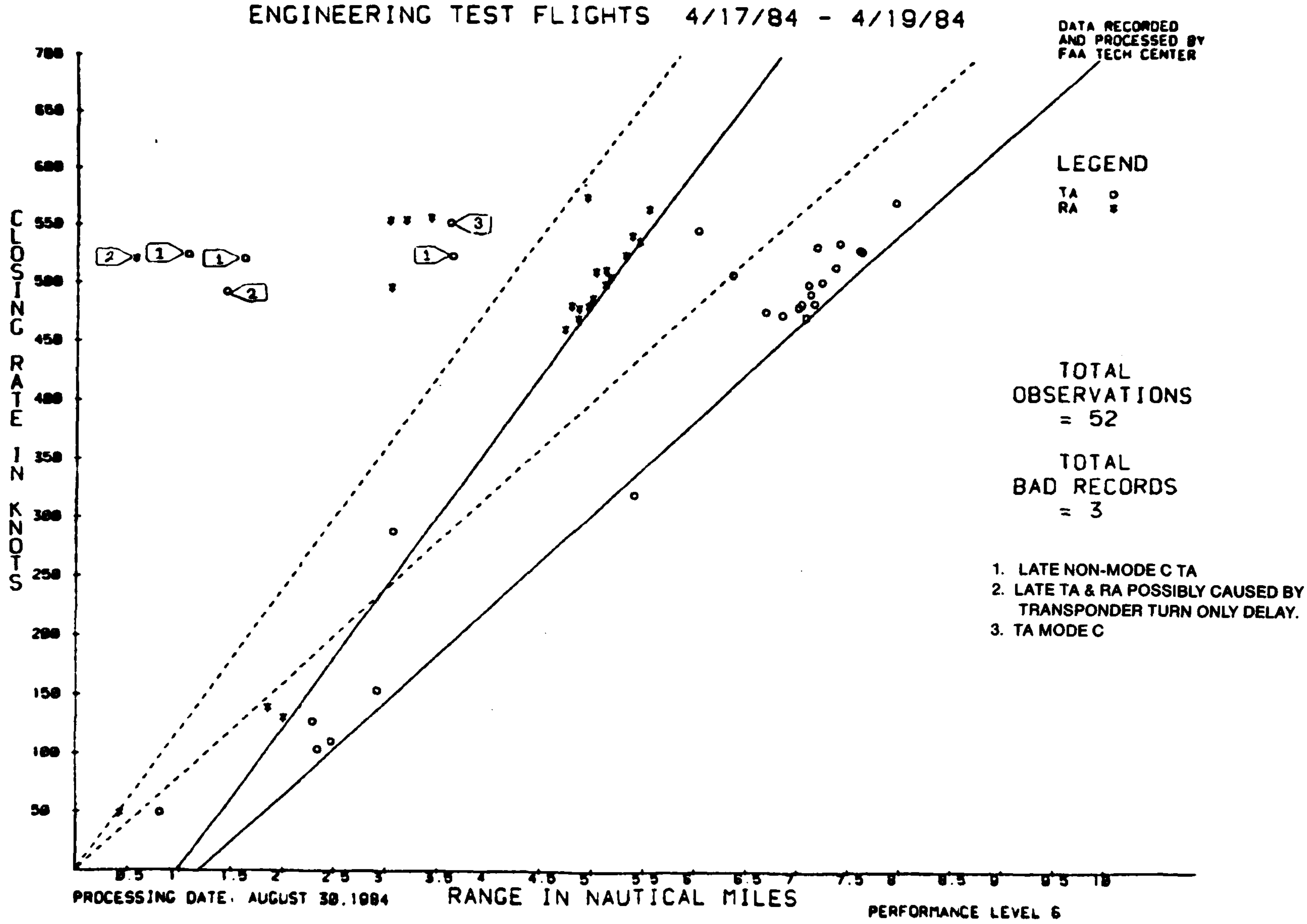
TOTAL ENCOUNTERS = 22

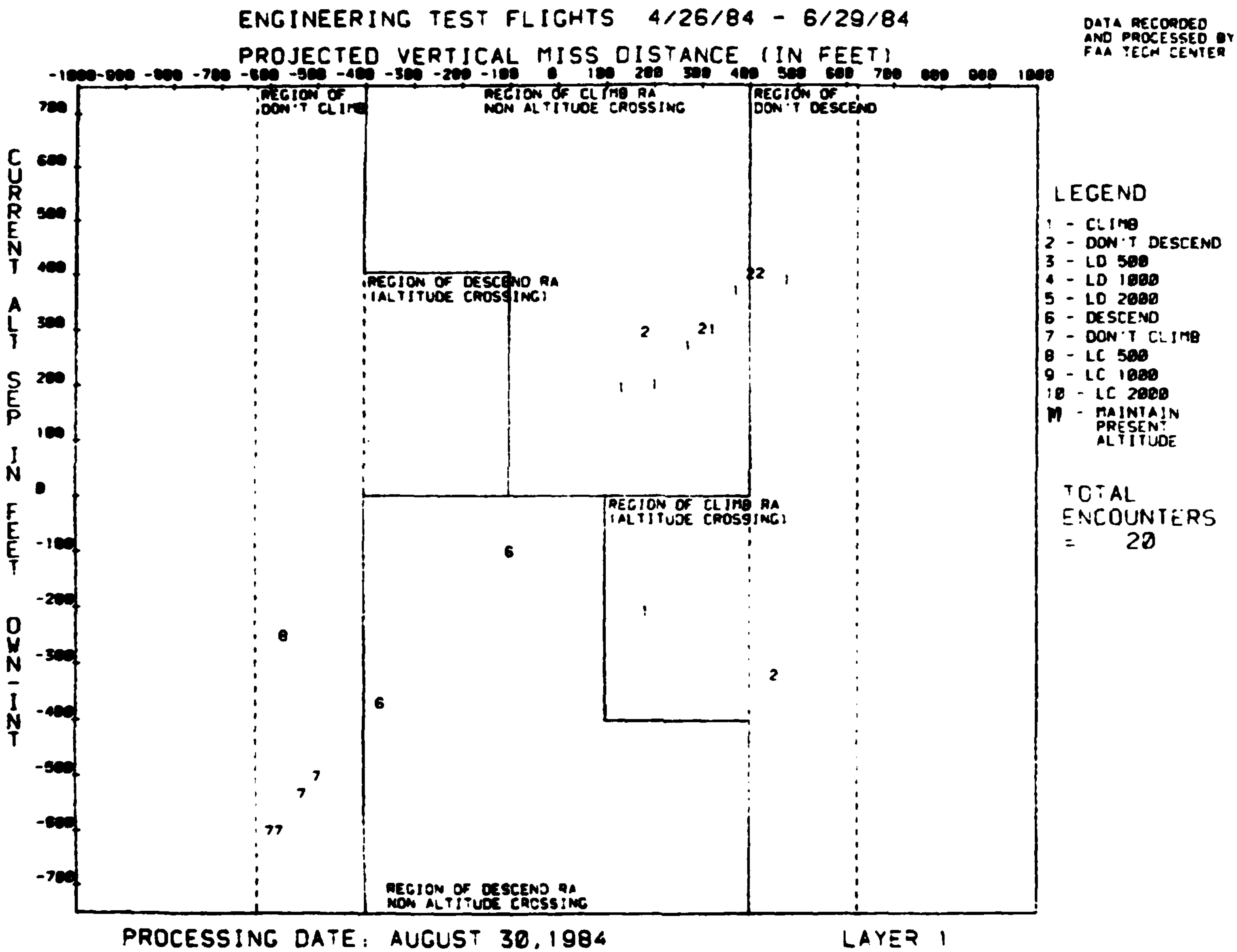

DATA RECORDED AND PROCESSED BY FAA TECH CENTER
ENGINEERING TEST FLIGHTS 4/17/84 - 4/19/84
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
VERTICAL MISS DISTANCE IN FEET
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
5
LD 2000
LD 1000
LD 500
1
1
REGION OF DON'T DESCEND RA
REGION OF CLIMB RA
REGION OF DESCEND RA
REGION OF DON'T CLIMB RA
LC 500
LC 1000
LC 2000
30
25
20
15
10
5
CPA
PROCESSING DATE, AUGUST 30, 1984
TRUTAU(IN SECONDS)
LAYER 1


DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER
ENGINEERING TEST FLIGHTS 4/17/84 - 4/19/84
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
VERTICAL MISS DISTANCE IN FEET
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
LD 2000
LD 1000
LD 500
4
1
1
REGION OF CLIMB RA
REGION OF DESCEND RA
LC 500
LC 1000
LC 2000
9
30
25
20
15
10
5
CPA
PROCESSING DATE AUGUST 30,1984
TRUTAU(IN SECONDS)
LAYER 2



ENGINEERING TEST FLIGHTS 4/17/84 - 4/19/84
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
LEGEND
TA o
RA *
TOTAL OBSERVATIONS = 69
TOTAL BAD RECORDS = 7
CLOSING RATE IN KNOTS
RANGE IN NAUTICAL MILES
PROCESSING DATE AUGUST 30,1984
PERFORMANCE LEVEL 5


ENGINEERING TEST FLIGHTS 4/17/84 - 4/19/84
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
CLOSING RATE IN KNOTS
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
RANGE IN NAUTICAL MILES
PROCESSING DATE, AUGUST 30, 1984
PERFORMANCE LEVEL 6
LEGEND
TA o
RA *
TOTAL OBSERVATIONS = 52
TOTAL BAD RECORDS = 3
1. LATE NON-MODE C TA
2. LATE TA & RA POSSIBLY CAUSED BY TRANSPONDER TURN ONLY DELAY.
3. TA MODE C

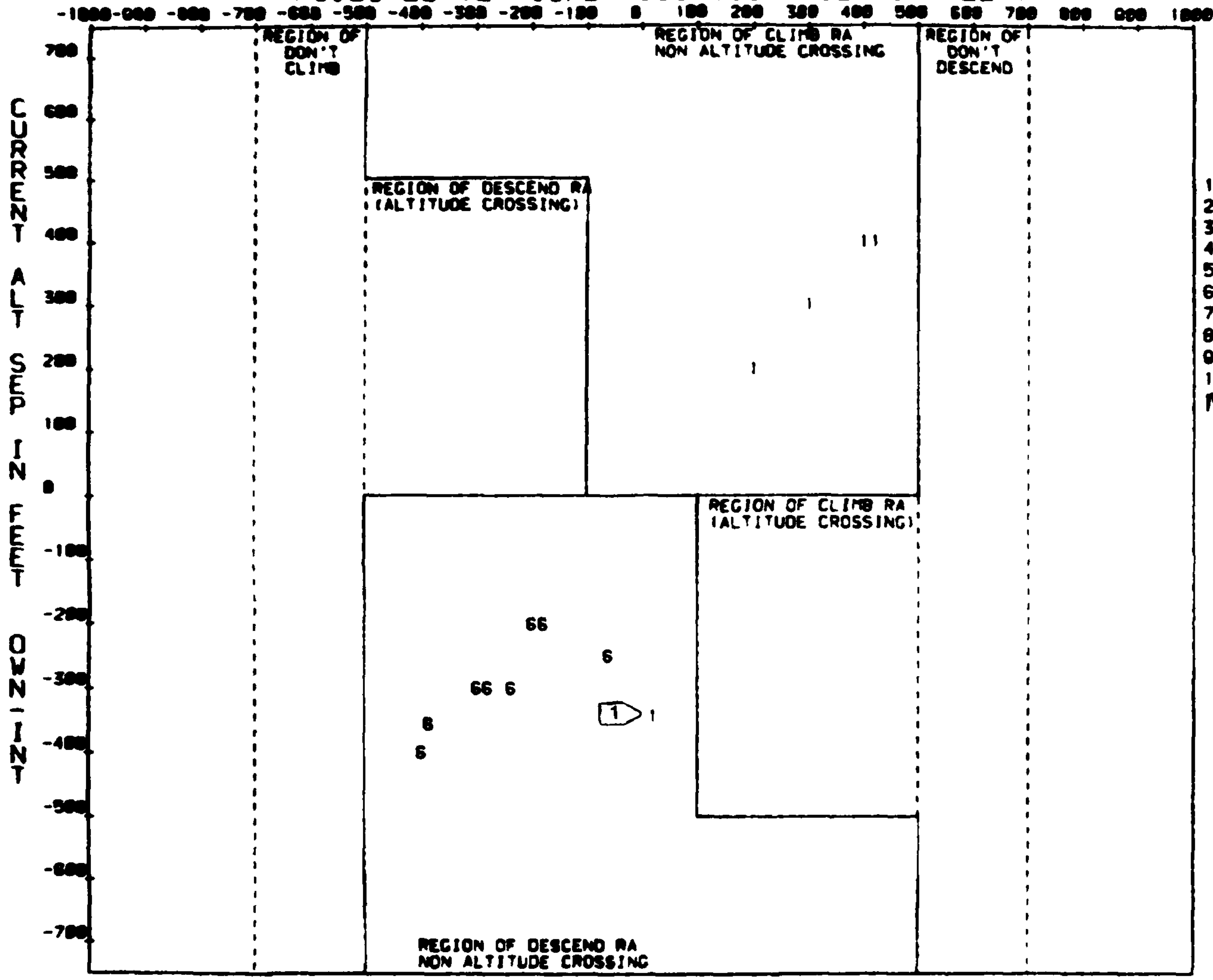


ENGINEERING TEST FLIGHTS 4/26/84 - 6/29/84
PROJECTED VERTICAL MISS DISTANCE (IN FEET)
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
CURRENT ALT SEP IN FEET OWN-INT
REGION OF DON'T CLIMB
REGION OF CLIMB RA NON ALTITUDE CROSSING
REGION OF DON'T DESCEND
REGION OF DESCEND RA (ALTITUDE CROSSING)
REGION OF CLIMB RA (ALTITUDE CROSSING)
REGION OF DESCEND RA NON ALTITUDE CROSSING
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
TOTAL ENCOUNTERS = 20
PROCESSING DATE: AUGUST 30, 1984
LAYER 1

ENGINEERING TEST FLIGHTS 4/26/84 - 6/29/84

PROJECTED VERTICAL MISS DISTANCE (IN FEET)

DATA RECORDED AND PROCESSED BY FAA TECH CENTER



PROCESSING DATE: AUGUST 30, 1984

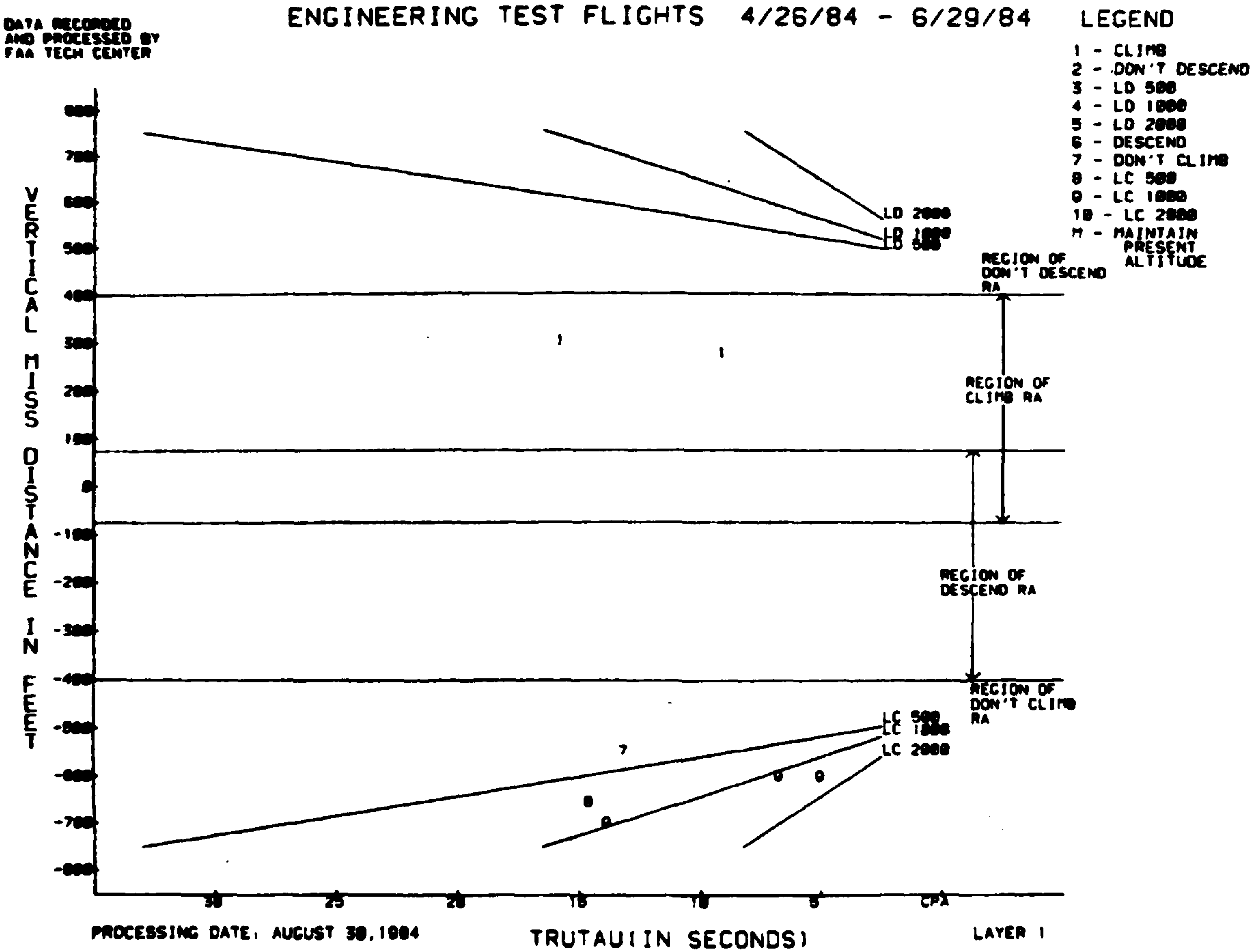
LAYER 2

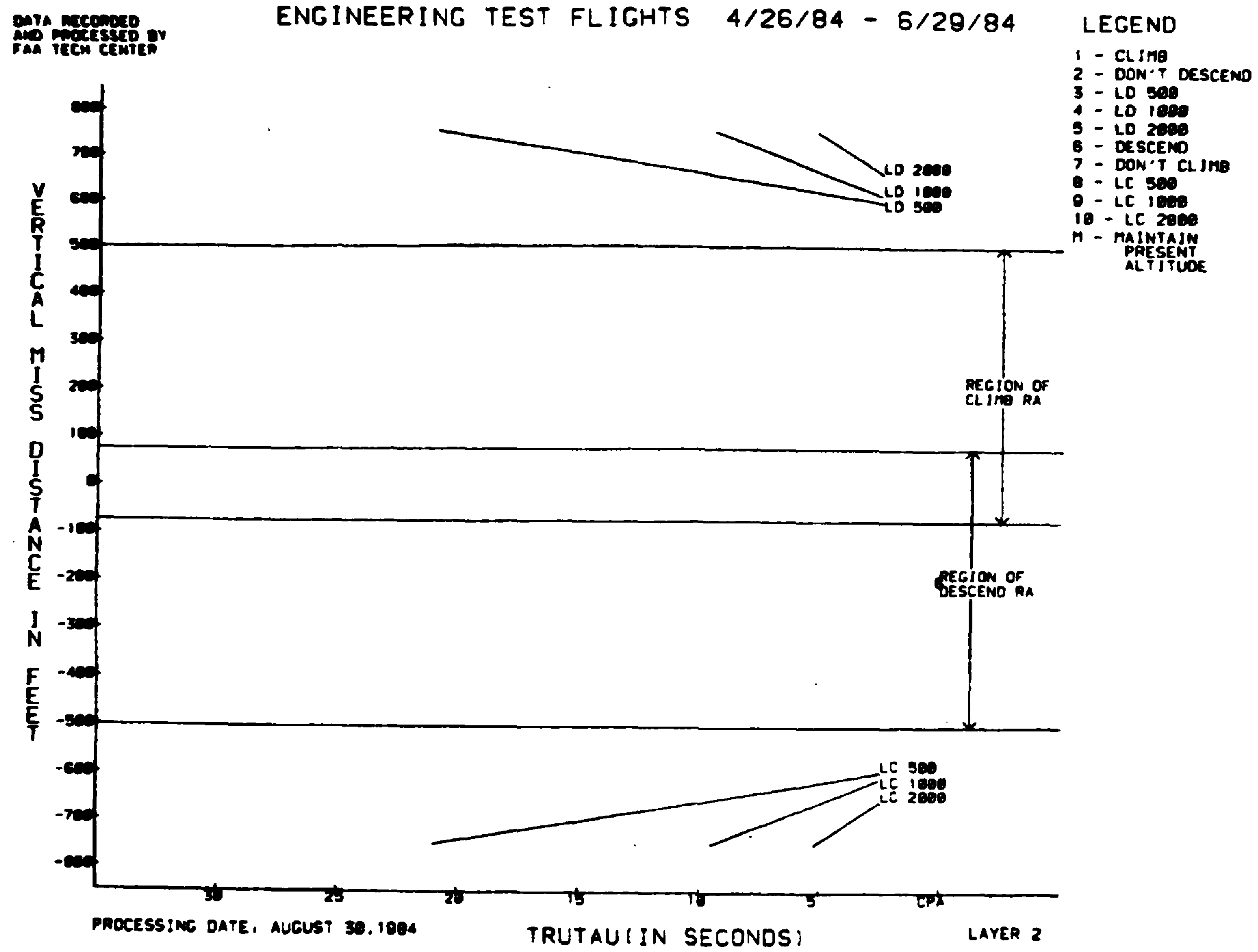
LEGEND

1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE

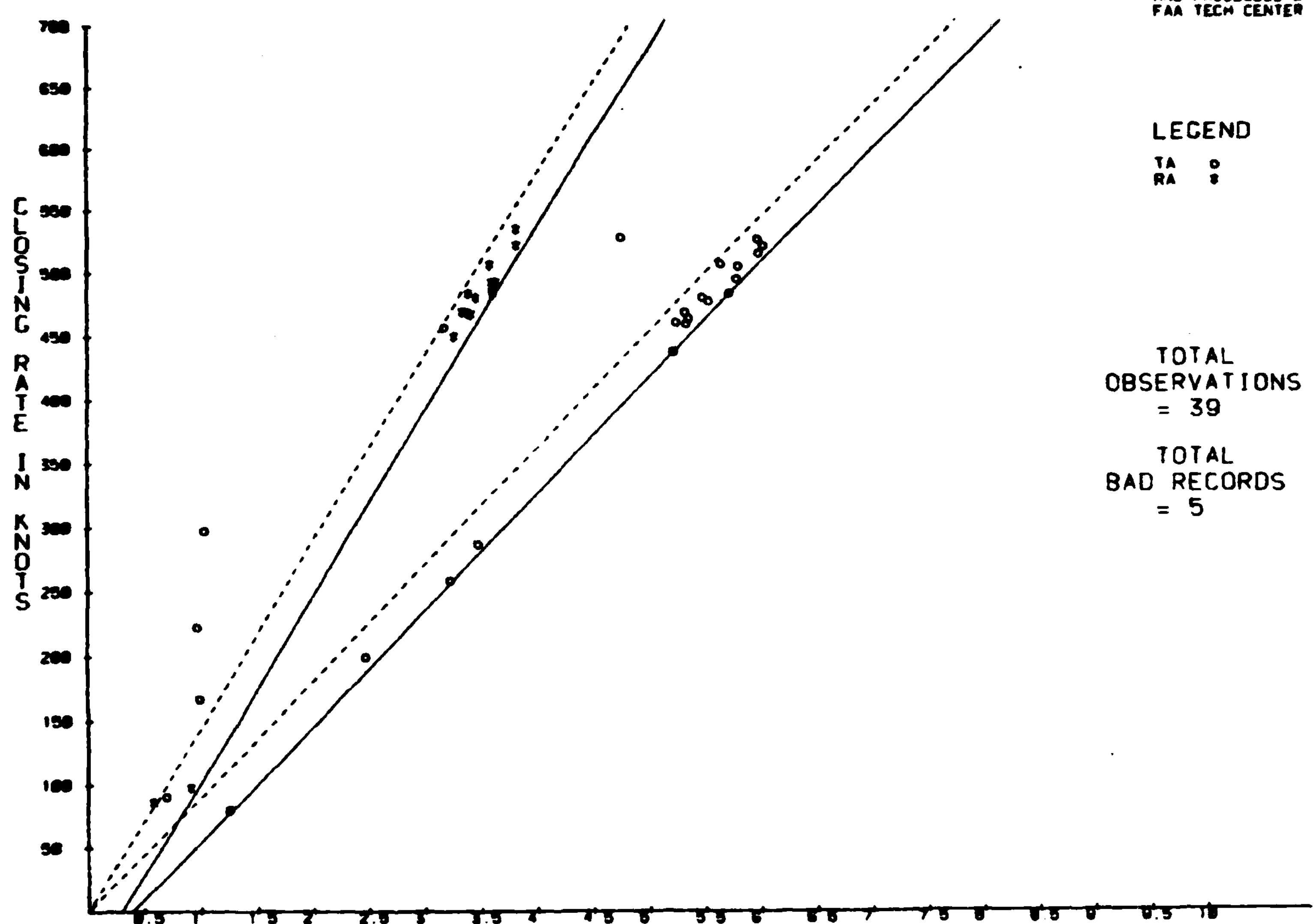
TOTAL ENCOUNTERS = 13

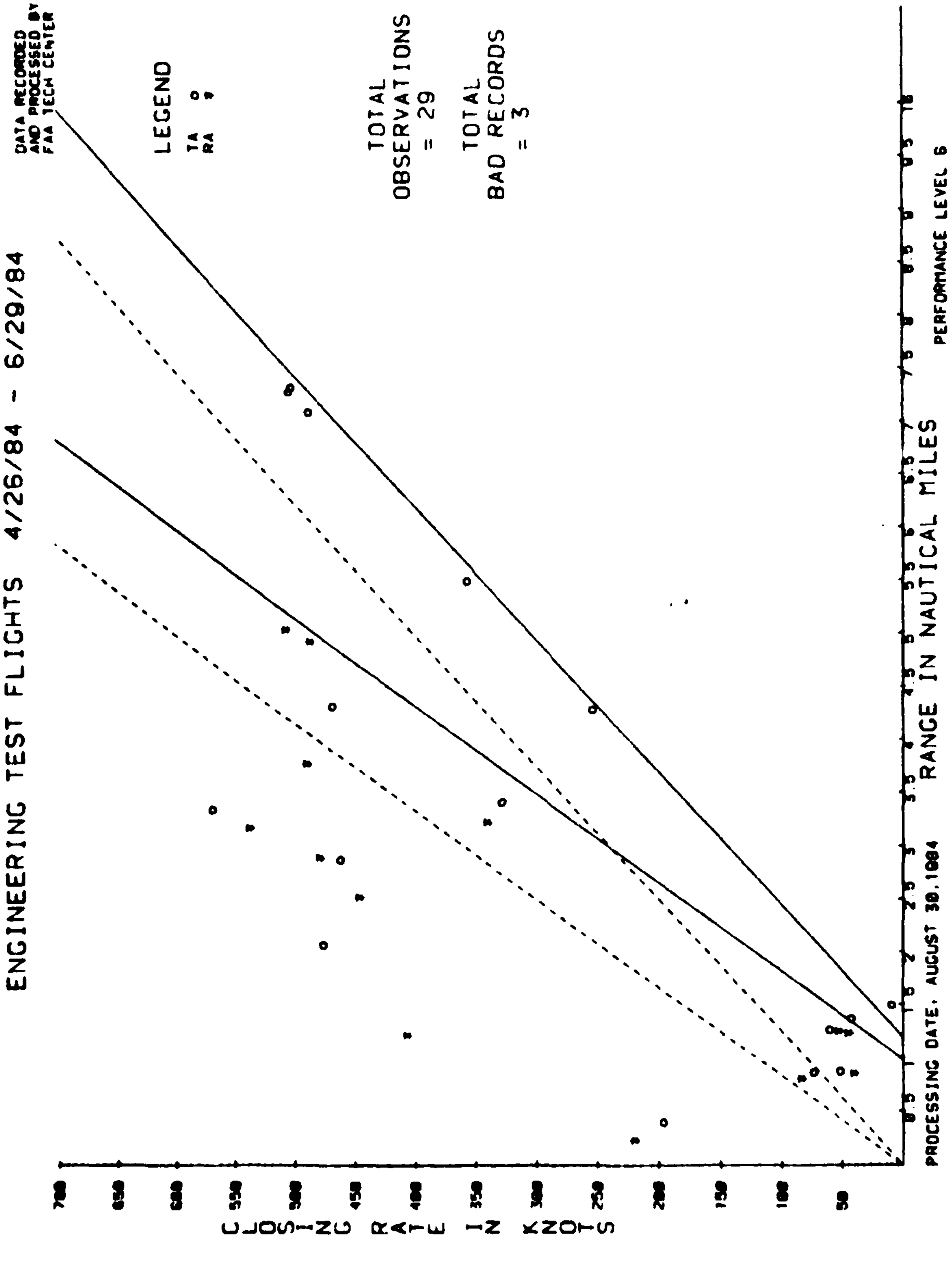
1. 6/08/84 ID 119 FTEG VERIFIED LOGICALLY CORRECT ALTITUDE CROSSING LOW FIRMNESS.


DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER
ENGINEERING TEST FLIGHTS 4/26/84 - 6/29/84
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
VERTICAL MISS DISTANCE IN FEET
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
LD 2000
LD 1000
LD 500
REGION OF DON'T DESCEND RA
REGION OF CLIMB RA
REGION OF DESCEND RA
REGION OF DON'T CLIMB RA
LC 500
LC 1000
LC 2000
30
25
20
15
10
5
CPA
PROCESSING DATE, AUGUST 30,1984
TRUTAU(IN SECONDS)
LAYER 1


DATA RECORDED
AND PROCESSED BY
FAA TECH CENTER
ENGINEERING TEST FLIGHTS 4/26/84 - 6/29/84
LEGEND
1 - CLIMB
2 - DON'T DESCEND
3 - LD 500
4 - LD 1000
5 - LD 2000
6 - DESCEND
7 - DON'T CLIMB
8 - LC 500
9 - LC 1000
10 - LC 2000
M - MAINTAIN PRESENT ALTITUDE
LD 2000
LD 1000
LD 500
REGION OF CLIMB RA
REGION OF DESCEND RA
LC 500
LC 1000
LC 2000
VERTICAL MISS DISTANCE IN FEET
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
30
25
20
15
10
5
CPA
PROCESSING DATE, AUGUST 30, 1984
TRUTAU (IN SECONDS)
LAYER 2

ENGINEERING TEST FLIGHTS 4/26/84 - 6/29/84




ENGINEERING TEST FLIGHTS 4/26/84 - 6/29/84
DATA RECORDED AND PROCESSED BY FAA TECH CENTER
LEGEND
TA o
RA *
TOTAL OBSERVATIONS = 29
TOTAL BAD RECORDS = 3
CLOSING RATE IN KNOTS
RANGE IN NAUTICAL MILES
PROCESSING DATE, AUGUST 30,1984
PERFORMANCE LEVEL 6

APPENDIX E

DOCUMENTATION RELATED TO THE TCAS PROGRAM

Copies of documentation are available from the Guidance and Airborne Systems Branch (ACT-140), Engineering Division, Federal Aviation Administration Technical Center, Atlantic City Airport, NJ 08405.

TEST/PROJECT PLANS.

1. Technical Center Letter Report: Test Plan for the Operational Evaluation of the Dalmo Victor TCAS II Prototype, October 1982, 128 pages.

2. Technical Center Letter Report: TCAS Operational Evaluation Project Plan, March 1983, 59 pages.

3. Technical Center Letter Report: TCAS Bench Test Plan and Related Test Configuration, 10 pages, Draft, unpublished.

SUMMARY REPORTS.

4. Dalmo Victor TCAS Prototype Test Flight June 15, 1983, Engineering Flight Test.

5. Dalmo Victor TCAS Prototype Test Flight June 26, 1983, Engineering Flight Test.

6. Dalmo Victor TCAS Prototype Test Flight June 22, 1983, Engineering Flight Test.

7. Dalmo Victor TCAS Prototype Test Flight June 24, 1983, Engineering Flight Test.

8. Dalmo Victor TCAS Prototype Test Flight July 19, 1983, Operational Evaluation Part 1, Engineering Flight Test.

9. Dalmo Victor TCAS Prototype Test Flight July 20, 1983, Operational Evaluation Part 1, Engineering Flight Test.

10. Dalmo Victor TCAS Prototype Test Flight August 11, 1983, Engineering Flight Test.

11. Dalmo Victor TCAS Prototype Test Flight October 4, 1983, Engineering Flight Test.

12. Dalmo Victor TCAS Prototype Test Flight October 11 - 12, 1983, Engineering Flight Test.

13. Dalmo Victor TCAS Prototype Test Flight November 8, 1983, Operational Evaluation Part 2.

14. Dalmo Victor TCAS Prototype Test Flight November 15, 1983, Operational Evaluation Part 2.

15. Dalmo Victor TCAS Prototype Test Flight November 17 - 18, 1983, Operational Evaluation Part 2.

16. Dalmo Victor TCAS Prototype Test Flight November 29, 1983, Operational Evaluation Part 2.

17. Dalmo Victor TCAS Prototype Test Flight November 30, 1983, Operational Evaluation Part 2.

TRIP REPORTS.

18. Acceptance Test at Dalmo Victor of SN02 TCAS - August 29 to September 2, 1983.

19. Repeat Acceptance Test at Dalmo Victor of SN02 TCAS September 19 to September 22, 1983. The report contains all tests and their results with particular emphasis on data loss. This report covers acceptance tests conducted August 29, September 2, and September 19 - 22, 1983.

20. Limited Acceptance Test at Dalmo Victor of SN02 TCAS October 30 to 31, 1983. This report contains eclipse computer printouts of data which show before and after results of problem resolutions. Particular emphasis was placed on the bearing processor and track establishment criteria.

21. TCAS Design Review for Critical Problem Resolution January 10 to 13, 1984. Difficult problems in the TCAS bearing subsystem forced a meeting of FAA, Lincoln Laboratory, and Dalmo engineers at Dalmo Victor to investigate the cause of the problems.

22. Acceptance Test at Dalmo Victor of SN01 and SN02 TCAS February 6 to 16, 1984. The report contains all tests and their results, with particular emphasis on the receiver performance, and data recording and playback on the Genesco recorder.

23. Acceptance Test at Dalmo Victor of SN01 and SN02 April 3 to 6, 1984. The report describes the test objectives and lists the outstanding problems.

INFORMATION MEMORANDA.

24. Dalmo Victor Prototype TCAS, dated June 3, 1983. Provided a summary of the first 2 weeks of Technical Center testing and listed requirements to show resolutions to problems observed during that time.

25. Status of the Technical Center Evaluation of Dalmo Victor TCAS II Industry Prototype, dated July 22, 1983. Describes the problems observed in part 1 of the operational evaluation (July 19 - 21, 1983).

26. Modifications and Deletions to the Dalmo Victor Acceptance Test Procedures dated September 7, 1983. Recommends deleting Mode stracking and power tests and adding logic tests to the September 19 - 22 acceptance test plan (ATP).

27. Technical Center Participation in the Factory Acceptance Test at Dalmo Victor, dated September 7, 1983. Documents Technical Center's participation in the acceptance test from August 29 to September 1, 1983.

28. Dalmo Victor Factory Acceptance Test, dated September 27, 1983. Recommended an order in which the tests of the ATP of September 19 - 22, 1983 could most efficiently be accomplished.

29. TCAS Planning Meeting Digest, dated September 29, 1983. Documented a meeting at the Technical Center of all support groups (e.g., radar facilities) planning to cooperate in the TCAS flight test.

30. Flight Test, October 7, 1983, dated October 8, 1983. Described the analysis of the flight data. The analysis included a breakdown of the encounters, and performance of the multipath rejection algorithm.

31. Engineering Flight Tests (Cockpit Display and Tests), dated October 24, 1983. An independent acessment by B. Billmann (ADA-10), TCAS, October 4 - 18, 1983.

32. TCAS Engineering Review, dated October 25, 1983. A summary of the Technical Center's engineering evaluation of SN02 TCAS conducted from October 3 - 18, 1983.

33. TCAS Problem Summary as of November 10, 1983, dated November 10, 1983. A summary of problems observed in the first operational flight of November 8, 1983.

34. Results of Transponder Measurements at the Technical Center, dated December 12, 1983. Contained the results of testing on several transponders from FAA test aircraft which showed poor TCAS tracking.

35. Action: TCAS II System Discrepancy and Evaluation Reporting Process, dated March 21, 1984. This letter established the implementation of the auto reporting system on November 30, 1983, and provided a comprehensive list status of the outstanding TCAS problems.

36. TCAS Operational Evaluation, Encounters Which Led to Aborts, dated April 1984. This memo provides a summary of the track histories of the target aircraft and lists the conditions of the three encounters which resulted in TCAS aborts.

37. Proposed Modification to the Dalmo Victor Prototypes, dated April 16, 1984. This memo proposed a solution to the dilemma created by the TCAS abort.

LETTERS.

38. Letter dated June 10, 1983, mailed to the subject pilots scheduled for the operation evaluation.

39. Letter to Lincoln Laboratory dated September 10, 1983, requesting comments of a matrix of the Technical Center's proposed engineering and operational evaluations.

40. Letter to APM-330 and Dalmo Victor dated December 20, 1983, with comments on the Dalmo Victor final acceptance test report dated December 9, 1983.

41. Letter to the MITRE Corporation containing histogram summararies of approach flight data, and a suggested change to the intruder-on-ground parameter designed to inhibit advisories against ground aircraft, as observed in Operational Evaluation and National Tour.

TROUBLE REPORTS.

42. Fifty-seven trouble or discrepancy reports were issued from May 1983 to April 1984. Of these, two remain outstanding, the others have been resolved (see Information Memoranda, item 35).

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